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ABSTRACT

These proceedings of the 2002 annual RESNA (Association for the Advancement of Rehabilitation Technology) conference include more than 200 presentations on all facets of assistive technology, including concurrent sessions, scientific platform sessions, interactive poster presentations, computer demonstrations, and the research symposium. The scientific papers included in the book address recent scientific research, practical designs, and case studies. Scientific content is grouped into the following eight categories: (1) technology for special populations, which includes "Robot Use and Cognitive Development in Children with Cerebral Palsy" (Petrina Duff and others), "Student Mentoring for the Design of Assistive Technology Devices" (Debra D. Wright and others), and "Assistive Technology Outcomes and Students with Mild Disabilities" (Dave L. Edyburn); (2) augmentative and alternative communication, which includes "A Language Activity Monitor for Digitized Speech AAC Systems To Support Evidence-Based Clinical Practice and Outcomes Measurement" (Marvin Indermuhle and others) and "The Learning Experiences of AAC Users: Results of an Internet-Based Focus Group Discussion" (Tracy Rackensperger and others); (3) computer access and use, which includes "Assessment of Computer Task Performance with Paediatrics and Low Vision" (Claude Vincent and others); (4) environmental accommodations; (5) functional control and assistance; (6) service delivery and public policy; (7) research and functional outcomes; and (8) seating and mobility, which includes "Educating Students of Occupational Therapy about Wheelchair Use: Comparison between Standard Curriculum and Skill-Acquisition

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Protocols" (Anna L. Coolen and others). The book includes papers from the student design competition and the student scientific paper competition, including "Development and Evaluation of a Thoracic Pressure Chair for a Student with Autism" (Andrew E. Anderson and others). (Papers include references.) (CR)

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# PROCEEDINGS

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# PROCEEDINGS
of the
RESNA 25th International Conference

## Technology & Disability:
Research, Design, Practice, and Policy

June 27-July 1, 2002

Hyatt Regency Minneapolis Hotel
Minneapolis, Minnesota

Richard Simpson, PhD ATP
Editor

Michael Lawler
David Wilkie
Conference Co-Chairs

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# Foreword

A forum to share information is what a conference is all about and RESNA is no exception. RESNA's annual conference offers Assistive Technology professionals a unique opportunity to network with peers and gain new knowledge about the needs of people with disabilities. This information exchange leads to better communication, improved understanding and overall improvements in the way Assistive Technology services are delivered.

The 2002 RESNA proceedings will surely become part of your reference library. Assistive Technology professionals and people with disabilities throughout the world will reference this body of knowledge thousands of times in the coming years. Using these cutting edge practices we will improve services, change policies and generally promote the well being of people with disabilities.

On behalf of the Organizing committee, the RESNA Meetings Committee, the Local Organizing Committee, RESNA members, conference attendees and people with disabilities everywhere, we salute the authors who share their knowledge within these pages.

Enjoy the conference, visit the exhibits – learn and have fun. Take advantage of the Twin Cities and all they have to offer, and if possible visit the excellent Assistive Technology centers located here.

Michael Lawler
Dave Wilkie
RESNA 2002 Conference Co-Chairs

Mary Binion
RESNA President

# Preface

Welcome to the RESNA 25th International Conference. This year's conference includes over 200 presentations on all facets of assistive technology through concurrent sessions, scientific platform sessions, interactive poster presentations, computer demonstrations, and the Research Symposium.

This Proceedings of the RESNA Conference attempts to capture some of the information that will be exchanged during the activities and events of the Conference. The scientific papers included in this document contain everything from recent scientific research to practical designs to case studies. Scientific content is grouped into 8 categories:

- Technology for Special Populations
- Augmentative and Alternative Communications
- Computer Access and Use
- Environmental Accommodations
- Functional Control and Assistance
- Service Delivery & Public Policy
- Research and Functional Outcomes
- Seating and Mobility

In addition, the winning papers for the Student Scientific Paper and Student Design competitions are also included.

RESNA 2002 resulted from the efforts of many people. Tony Langton, in particular, has led the planning and organizing at both the local and national levels. Thanks go to Ramon Castillo, coordinator for the concurrent sessions which parallel the scientific sessions, and to the topic coordinators for the review process of the scientific papers: Alex Mihailidis, Bruce Fleming, Sharon Ferrell, Molly Story, Holly Yanco, Christine Appert, Shirley Fitzgerald, Laura Cohen, and Ann Eubank. Thanks also go to the numerous reviewers of the individual scientific papers for their efforts in determining the final program. Molly Story and Ed Steinfeld are to be commended for their leadership in shaping the Research Symposium on Universal Design. As always, the efforts of Susan Leone, Larry Pencak and the rest of the RESNA staff are greatly appreciated.

Enjoy the Conference.

Richard Simpson, PhD ATP
Chair, Scientific Program

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# Table of Contents

**Technology for Special Populations (Topic 1)**

Building Natural Cross-Disability Access into Voting Systems ... 2
Real-Time EOG Filtering for Control of an Ocular Prosthesis ... 5
Sidewalk Performance of GPS Blind Navigation ... 8
Using Simulation to Predict and Solve Design Problem ... 11
An Intelligent Cognitive Orthosis for Person with Moderate-To-Severe Dementia: Results and Recommendations ... 14
Robot use and Cognitive Development in Children with Cerebral Palsy ... 17
Enabling Technologies for People with Dementia ... 20
Development of the Game CYCLE Exercise System ... 23
Stretch and Exercise Station ... 26
Momentum: A Novel Hand-Powered Cycle ... 29
The Multi-Port Sip-and-Puff Switch ... 32
Student Mentoring for The Design of Assistive Technology Devices ... 35
Seeing MS Office in a Whole New Light: A Case Study on turning Everyday into Low Vision Tools ... 38
Assistive Technology Outcomes and Students with Mild Disabilities: Policy Initiatives ... 41
Design of Assistive Art Devices for High School Students with Disabilities ... 44
A Feedback Enhanced Assistive Bowling Device ... 47
Design of a Switch Activated Ball Tosser ... 50
The Audible Counter ... 53
DreSS: The Dressing Support System ... 56
Counter for the Visually and Mobility Impaired ... 59
The Task Cueing Timer ... 62

**Augmentative and Alternative Communication (Topic 2)**

Continuous Korean Sign Language Recognition Using Gesture Segmentation and Hidden Markov Model ... 66
A language Activity Monitor for Digitized Speech AAC Systems to Support Evidence-Based Clinical Practice and Outcomes Measurement ... 69
The Learning Experiences of AAC Users: Results of an Internet-Based Focus Group Discussion ... 72
Acquisition of Scanning Skills: The Use of an Adaptive Scanning Delay Algorithm Across Four Scanning Displays ... 75
Reliability Study of Language Samples Using Software to Support the Transcription of Digitized Speech AAC Systems ... 78
The AAC Rate Index in Clinical Practice ... 81
The Development of an AAC Language Sample Library to Support Evidence-Based Practice ... 84
A Model for AAC Evidence-Based Clinical Practice ... 87

Leveraging Word Prediction to Improve Character Prediction in Scanning Configuration 90
Effective Participation of Persons Using AAC in Mixed Group User and Non-Users of AAC 93
Connecting AAC Device via Mobile Handset to the Outside World 96

**Computer Access and Use (Topic 3)**

Web Page Usability Test for Blind 100
W3C User Agent Accessibility Guidelines 103
Mouse Emulation Using the Wheelchair Joystick: Preliminary Performance Comparison Using Four Modes of Control 106
Automatic Customization Software for Computer Head Controls 109
User Performance with Speech Recognition Systems 112
A Method Measuring Client Performance with Speech Recognition 115
"Assessment of Computer Task Performance" with Paediatrics and Low Vision 118
An Assistive Technology Outcomes Primer 121
Access X and On Screen Keyboard for LINUX 123
Pilot Study on User Performance with Speech Recognition Systems 126
Investigating Relationships between User Performance and Scan Delays in Aids that Scan 129

**Environmental Accommodation (Topic 4)**

Framework for Systematic Evaluation of Job, Worker, and Intervention Combinations 134
Implement of Ergonomic Interventions in Office Environments: A Follow-Up Review 137
An Assessment Tool For Environmental Control Provision 140
Measuring the Cost Utility of Electronic Aids to Daily Living 143
Universal Design Exemplars 146
Future Housing Now: The Next Generation 149
An Inrfrared Elevator Control System 152
Enhanced Quality of Life through the Application of Universal Design Principles to Outdoor Recreation Opportunities 155

**Functional Control and Assistance (Topic 5)**

The Design and Kinematic Evaluation of Passive Wearable Upper Extremity Orthosis 160
A Backriveable Robot for Measuring and Manipulating Stepping 163
Evaluation of Sensors for A Smart Wheelchair 166
Dynamic Pressure Relief for the Wheelchair User with Long-Term Therapeutic Neuromuscular Electrical Stimulation 169
Development of a Novel Type Rehabilitation Robotic System Kares II 172
WREX- A Case Study of the Wilmington Robotic Exoskeleton 175
Establishing Design Criteria for Input Control Systems for Individual with Quadriplegia 178
The Effects of Trunk Stimulation on Seated Workspace 181

**Service Delivery & Public Policy (Topic 6)**

Perceived Responsibilities of Rehabilitation Professionals and Stakeholders in Distance Delivery of Continuing Education ............ 186
Integration of AT Education by Rehabilitation Professionals ............ 189
Online Resource for Teaching Universal Design ............ 192
A comparison of Assistive Technology Expertise Across Urban, Suburban and Rural Wisconsin School Districts ............ 195
Accessible Telecommunication Information for People with Communication Impairment ............ 198
Problem-Based Learning for Assistive Technology Education II ............ 201
Paths to Market ............ 204
Critical Success Factors in Technology Transfer ............ 207
Project Impact Post-Secondary Accessibility Discoveries ............ 210
A Description of Need for inpatient Assistive ............ 213
Pediatric Powered Mobility: Preliminary Results of a National Survey of Provides ............ 216
Design of Clinical Observation Experience Program for Undergraduate Students in Engineering ............ 219

**Quantifying Function and Outcomes (Topic 7)**

Maintaining Balance in Seated Reaches ............ 224
Using the WWW to Study the Experiences of Person who Use Wheelchairs: Local Area Versus Distant Participants ............ 227
Influence of Wheelchair Service Dogs on Human Assistance Needs in Basic and Instrumental Activities of Daily Living ............ 230
Development and Reliability Testing of a Clinical Rationale Measure of Seating and Wheeled Mobility Prescription ............ 233
The Development of Digital Human Models of People with Disabilities for use by Designers and Clinicians ............ 236
Assistive Technology Outcome Assessment Prototypes: Measuring "Ingo" Variables of "Outcomes" ............ 239
Measuring Consequential Validity of an Assessment Instrument Using Human Judgement ............ 242
The Functional Evaluation in a Wheelchair (Few) Instrument: Test-Rest Reliability and Cross-Validation with Consumer Goals ............ 245
The Application of Optical Sensors for Quantifying Electric Powered Wheelchair Driving Skill ............ 248

**Seating and Mobility (Topic 8)**

Assessing The Influence of Assistive Technology on Participation ............ 252
An Obstacle Course for the Assessment of Wheelchair Mobility Performance ............ 255
Wheelie Training: Does Adding the Proactive Balance Strategy Improve Outcomes? ............ 258
Educating Students of Occupational Therapy about Wheelchair Use: Comparison between Standard Curriculum and Skill-Acquisition Protocols ............ 261

Does a Brief Formalized Period of wheelchair Skills Training Improve Outcomes? ........ 264
Wheelchair Skills Training: The Next Frontier ........ 267
Wheelchair Tiedown Loads and Occupant Restraint Loads Associated with Various Occupant Sizes in Frontal Impact Testing ........ 270
Issues Related to the location of a Universal Interface for Automated Wheelchair Securement ........ 273
"Safe wheelchair transportation for school aged Children-Current issues and Panel Discussion"(?)
Propulsion Work and Power Differences in Wheelchair Users with Greater Evidence of Shoulder Pathology at Follow-up ........ 276
Muscle Imbalance with Manual Wheelchair use in Individuals with Multiple Sclerosis ........ 279
A Fatigue Analysis during Wheelchair Propulsion in Patients with Multiple Sclerosis ........ 282
Physiological Comparison of a Pushrim Activated Power Assist Wheelchair and Traditional Manual Wheelchair Propulsion among persons with Tetraplegia ........ 285
Use of the Independence ™ 3000 IBOT ™ Transporter at Home and in the Community: A Pilot Study ........ 288
Comparison of Virtual Electric Powered Wheelchair Driving Using A Position Sensing Joystick and an Isometric Joystick ........ 291
Review of Alternative Power Sources for Powered Wheelchairs ........ 294
Design of a Forward Folding Ultralight Wheelchair ........ 297
Mechanical Properties of Polyurethane Elastomers in an Oblique Angled Suspension Caster Fork for Wheelchairs ........ 300
Analysis of Whole-Body Vibrations of Suspension Manual Wheelchairs: Utilization of the Absorbed Power Method ........ 303
Wheelchair Wheel Wash System ........ 306
A Systematic Process for Successful Technology Transfer ........ 309
Consumer Preferences for Wheelchair Wheels ........ 312
Wheelchair Garage Access System ........ 315
Disturbances Induced by Wheelchair Casters When Driving Backwards ........ 318
Durability and Value of Powered Wheelchairs ........ 321
Design Development of New Folding Commode-Shower Wheelchair ........ 324
Using Telerehabilitation to Aid in Selecting a Wheelchair ........ 327
Viscoelastic Properties of buttock Soft Tissues with Pressure Ulcer Susceptibility ........ 330
A Survey of Alternating Pressure Seat Cushions ........ 333
Wheelchair Braking Biomechanics ........ 336
Gender Difference in the Segmental Power and Energy of Manual Wheelchair Propulsion ........ 339
Comparison of Hybrid III ATD and Wheelchair User at Selected Speed ........ 342
Effect of Gloves on Wheelchair Pushrim Kinetics in a Heterogenous Population ........ 345
Relationship of Wheelchair Pushrim Forces and Pressures at the Body-Seat interface in Manual Wheelchair Users ........ 348
A Video-Based analysis of "Tips and Falls" during Electric Powered Wheelchair Driving ........ 351
A Power-Assisted System for a Thai Style Tricycle ........ 354

24 Hour Positioning-The Missing Link ....... 357
Time Sequence of Pressure Changes During Weight Relief Activities on Different Wheelchair Cushions ....... 360

**RESNA Student Scientific Paper Competition**

Effectiveness of Rear Suspension in Reducing Shock Exposure to Manual Wheelchair User During Curb Descents ....... 365
Determining the Effectiveness of the Game CYCLE System as an Exercise Device ....... 368
Wheelchair Propulsion Biomechanics in Patients with Multiple Sclerosis ....... 371
Trunk Movement Adaptations during Wheelchair Propulsion at two Speeds and Load Conditions ....... 374
Kinematics State of the Hand at Impact with the Wheelchair Handrim as a Function of Handrim Compliance ....... 377

**RESNA Student Design Competition**

Development and Evaluation of a Thoracic Pressure Chair for A Student with Autism ....... 383
An Assistive Bowling Device for Persons with Disabilities ....... 386
Magic Timer: A Multi-sensory Assistive Innovation ....... 389
Infant Patting Device ....... 392
Custom Walker with Rotational Hip Support ....... 395

# Technology for Special Populations
# (Topic 1)

# BUILDING NATURAL CROSS-DISABILITY ACCESS INTO VOTING SYSTEMS

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## ABSTRACT

In recent years our nation has steadily increased both the requirements for accessibility of mainstream electronic technologies and the effectiveness of the interfaces. In particular, progress has been made in the areas of creating interfaces that can be used by the general population of people with disabilities and not just those that are familiar with and adept with technology. Probably the greatest challenge however comes in trying to develop electronic voting systems, which are cross disability accessible. This paper describes a design approach and prototype, which seeks to provide cross disability accessibility as a natural part of the interface used by everyone. Implications for usability and acceptance by the individuals with mild disability and individuals who are aging is discussed.

## BACKGROUND

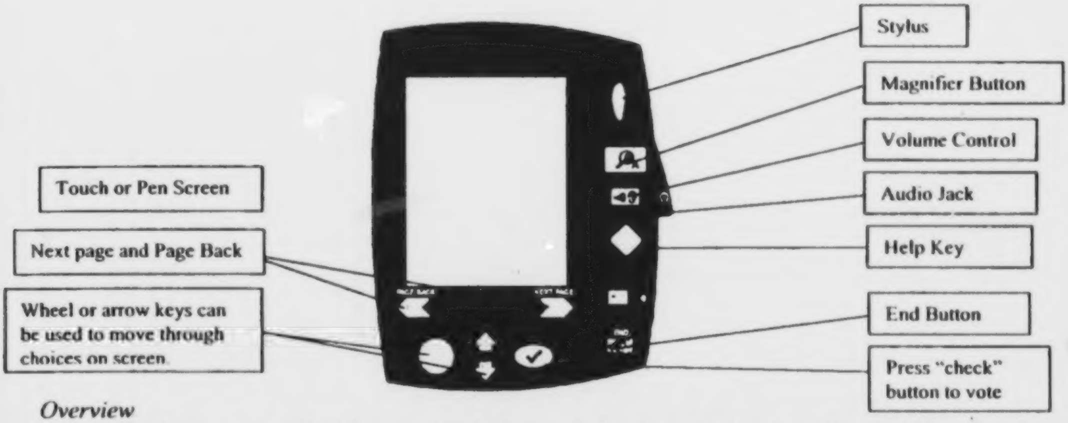
Electronic voting systems present a number of challenges, which are not faced in most other technology areas. First, individuals only use the devices rarely. Secondly, they have little or no training prior to encountering a new voting system and many are unlikely to admit when they have problems or seek help. Thirdly, voting is carried out in private. As a result it is not possible to ask someone to help without both breaking the privacy of the vote and without being conspicuous.

Older voters in particular can present challenges. Many do not realize they have functional limitations which could cause them to make errors. Some individuals find it difficult to admit their disability and try to just use things as they are. Others know they have a problem but do not want to admit it to others, especially local poll workers they may know. Some individuals who are older are not used to systems with screens that change, offer different choices or that include on-screen buttons. They may also have difficulty adopting and adapting to different paradigms for voting. Voting systems that do not look like what they are used to can cause them to "push back" and/or avoid the technology.

## NATURAL ACCESSIBILITY

The approach used in this design is termed "natural accessibility". With this approach there are no special "disability access" modes. There is a single mode of operation which has flexibility built into it. This flexibility allows the user to adjust or choose the interface approach that they find easiest. In the same way that many operations on a computer can be done either from a keyboard or with a mouse, the prototype allows operation using either direct touch to the screen with a stylus or the use of buttons to move and select items on the screen.

Because there is only one mode of operation there is only one set of instructions. The goal is to create a design that requires minimal instructions, with additional help available at any time.



*Overview*

The first prototype implementation is shown in Figure 1. Instructions directly below this screen tell the user that they can vote by either touching their choices on screen or by using the buttons immediately below the screen to move up and down through the candidate list and mark their choice using the check button. Two buttons located at the bottom corners of the screen are used to turn the pages of the ballot.

Those who have sufficient visual and physical skills to use the touch screen can simply turn the pages of the ballot using the Next Page (or Page Back) button and touch their choices on screen. Each race or referendum is on a separate "page". Voters can step through the pages without voting if they choose and can freely page back and forth through the ballot. If they wish to jump to the end of the ballot, they can press the red "END" button in the lower right corner of the device.

At the end of the Ballot, the voters are provided with a summary of all of the races along with the candidates they have chosen for each race. At this point they can review their choices and make changes. They can jump back and vote for a race that they skipped, or they can jump back and change any vote they have made.

The voting system has an enlargement button which can increase the size of the fonts in three steps up to 30 pt. It also has a volume control which is used with the voice output headphone feature. However, the voting tablet can be used in a completely silent fashion as well.

*Use by voters with Functional Limitations.*

For individuals with low vision, - the 3 step zoom enlargement can be used to increase the visual display up to 30 pt type. Because the device does not have different modes, the visual and auditory features can work together seamlessly. Thus, voters can use both their vision and hearing to guide and confirm their voting.

Individuals who are blind - can use either the up and down buttons or the wheel near the bottom edge of the device to move back and forth through the choices on screen. As they move through the choices and text on screen, the text is read aloud to the individual using headphones. The oval check button is used to either mark or unmark choices that have been read to them. In order to make the process straight forward, physical page turning buttons are used and are provided directly below the screen (rather than using on-screen buttons that the person would have to arrow down to in order to activate).

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Individuals who are hard of hearing - can use the device in a completely silent fashion. However, if they have low vision (or blindness) and are hard of hearing, they are able to use the audio output feature and the volume control to hear the output clearly. The Voting Tablet also has a headphone jack to allow individuals to plug in special assistive listening devices or direct connections to their hearing aid or cochlear implant.

Individuals who are deaf - can use it in its standard silent fashion. The language used on screen (except for the referendum measures) is carefully chosen to maximize understanding for individuals for whom English is a second language. The buttons all have a tactile feel so that there is no reliance on audio to operate the device.

Individuals with physical disabilities - are able to use the arrow keys, which are positioned close to the bottom edge and spaced to facilitate operation with physical disabilities. Each of the buttons has a concave center to facilitate operation by hand sticks, mouse sticks, stylists, etc.

For individuals with cognitive disabilities - the voting system has been designed using graphic illustrations of its operation and audio confirmation of all instructions and selections. In addition, auto-cuing is proved by the device whenever the voter stops interacting with the device.

For individuals who have reading difficulties or who are unable to read for any reason,- the audio feature provides a convenient, effective mechanism for them to be able to listen to their choices and vote independently .

## INITIAL FEEDBACK

The Voting Tablet development is still underway. The process involves continual evaluation and change based upon feedback from users. Preliminary feedback on the software portions completed has shown that the basic operation of the device is fairly straightforward. However, some individuals who are blind exhibited nervousness when told that the device has a touch screen for sighted users. Some users find that they bump the screen while they are looking for the tactile buttons that are below the screen. Others are afraid to come near the device for fear that they will touch the screen and cause it to do something by accident. This problem is exacerbated by the nature of voting. Individuals are quite concerned about casting an inadvertent vote by accidentally bumping the screen. And they feel they may not be aware of it if voting privately.

To address this concern, an alternate strategy to the touch screen is being explored. With this approach a pen-sensitive screen is used, rather than a touch-sensitive screen. Individual voters can then either vote by picking up the stylus and marking choices directly on the screen, or they can vote by using the buttons located below the screen. Because the screen would not be touch-sensitive with this approach, users with poor vision, poor motor control or who are blind do not have to worry about accidentally touching the screen. The screen is completely inert unless the voter picks up the pen-like stylus and uses it to vote.

## ACKNOWLEDGMENTS

This research is funded by the National Institute on Disability and Rehabilitation Research grant # H133E980008

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# REAL-TIME EOG FILTERING FOR CONTROL OF AN OCULAR PROSTHESIS

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[1]Department of Electrical and Computer Engineering, University of Alberta
[2]Faculty of Rehabilitation Medicine, University of Alberta

## ABSTRACT

Current ocular prostheses are distracting to the observer because they are stationary. To address this problem, an ocular prosthesis that tracks the movements of the natural eye has been developed. To enable tracking, the position of the natural eye is sensed using the electrooculogram (EOG). The EOG signal is passed through a biopotential amplifier to reduce common mode artefacts. Several filters for de-noising the EOG in real-time were compared, and an FIR Hanning filter was found to introduce the least amount of signal distortion and lag to eye movements extracted from a model saccadic EOG signal.

## BACKGROUND

When an individual loses an eye to injury or disease, modern prosthetic eyes provide a good cosmetic solution. However, since the prosthetic eye is stationary the presence of the prosthesis becomes evident when the individual moves his or her natural eye. The unwanted attention elicited by the prosthesis can cause the individual considerable distress (1). We have developed an ocular prosthesis that provides natural-looking movement of the prosthetic eye. The system detects the position of the natural eye and drives the prosthetic eye to track the movements of the natural eye. The prosthesis is contained within the orbit so that it is not noticeable. The volume of the orbit limits the space and processing power that can be used to implement the system.

The electrooculogram (EOG) is used to detect eye movements. The EOG is the externally sensed corneo-retinal potential, which is proportional to eye position of the real eye. The EOG is recorded using silver/silver chloride bipolar temporal electrodes and a forehead reference electrode (2). The EOG is a suitable method for detecting eye movement in this application because it can be sensed non-invasively, and a control signal can be obtained from the EOG with the limited processing power available in the implanted system.

The magnitude of the EOG signal is about 1 mV. To increase signal strength, the EOG is amplified with a biopotential amplifier that provides a gain of 200 in the frequency band of the EOG and a high common mode rejection ratio. The EOG signal is then used as a control signal to drive the ocular prosthesis. The system is illustrated in Figure 1. Work to date has shown that this design is feasible in the laboratory (3). However, sensing the EOG in a clinical system presents two major challenges. First, the EOG is subject to DC drift due to changes in skin resistance and electrode position. Second, the EOG is corrupted with non-stationary noise from other biopotentials (ECG, EMG, and EEG) and non-biopotentials such as 60 Hz line noise. The latter problem is addressed in this paper.

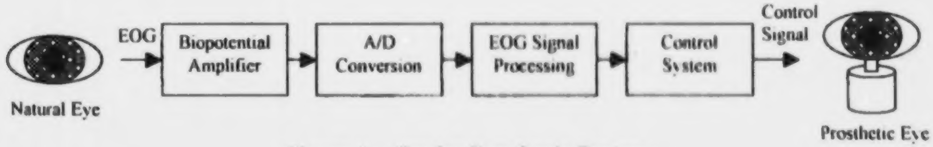

Figure 1 – Ocular Prosthesis System

Saccadic and miniature eye movements are the most frequently occurring eye movements during normal social interaction (4). Eye movements of less than 1 degree are not noticeable to the observer, so only saccades with a magnitude of more than 1 degree will be tracked by the prosthesis. Miniature eye movements will not be tracked since they have a magnitude of less than 10 minutes of arc. The minimum time to move the natural eye through 1 degree of rotation is about 1 ms (4). Therefore, the lag of the signal processing and control system for the prosthetic eye must be less than or equal to 1 ms.

The EOG is used in psychology research to track eye movements, and in sleep research to count eye movements during sleep. The literature from these fields contains methods for processing the EOG offline to obtain eye movement data, and real-time methods for counting eye movements. Since the ocular prosthesis will be worn full-time by the person and will be implanted in the eye socket, eye movement data must be obtained in real time and with a limited amount of storage capacity and signal processing power. Therefore, this paper concentrates on real-time techniques for processing the EOG to obtain eye movement data.

Several types of signal processing methods were considered for de-noising the EOG. The adaptive EOG filtering methods used by Bankman et al (5) and Zhu (6) were rejected because they do not perform well with non-stationary noise when only a single EOG channel is available. Time-frequency methods such as the short time Fourier transform are too computationally intensive. Low-pass filters such as the low-pass Chebyshev II filter used by Huebner et al (7) have been used successfully to process the EOG.

## RESEARCH QUESTION

Based on this background, we sought to find a suitable filtering method for extracting eye movements from the saccadic EOG for use as a control signal in the implanted ocular prosthesis.

## METHOD

The typical method of de-noising the EOG is to use a low-pass Butterworth filter. This method was compared with low-pass Chebyshev II and Hanning filters. Infinite impulse response (IIR) Butterworth and Chebyshev II filters were implemented digitally using the bilinear transformation. Butterworth filters are maximally flat in the pass band, and have a relatively wide transition region. Chebyshev II filters are flat in the pass band and have equiripple in the stop band. They have a narrower transition region than Butterworth filters. A finite impulse response (FIR) filter was implemented using a Hanning window. FIR filters can be realized efficiently in hardware, but can result in a longer filter length than the equivalent IIR filter. A cut-off frequency of 10 Hz was used with each filter.

A 10-degree model saccade was constructed and then contaminated with EOG noise (5). The noise was obtained by recording the EOG while the subject's eyes were stationary and passing the signal through an anti-aliasing filter with a cut-off frequency of 50 Hz. The signal was then sampled at the Nyquist rate of 100 Hz. The noisy saccade was filtered with the Butterworth, Chebyshev II and Hanning filters described above.

## RESULTS

The filter order, eye movement duration, and maximum lag of the filtered signal in each case were compared to that of the original saccade to evaluate the performance of each filter. The eye movement duration was measured as the 10% - 90 % rise time of a saccadic eye movement. The lag was measured as the time difference between the midpoint of the original saccade and the midpoint of the filtered saccade. As can be seen in Table 1, the Chebyshev II and Hanning filters have a lower filter order than the Butterworth filter. The Hanning filter results in a signal with a less distorted duration and less lag than the Chebyshev II filter.

Table 1: Comparison of Filtering Methods

| | Original Saccade | Butterworth | Chebyshev Type II | Hanning |
|---|---|---|---|---|
| Filter Order | n/a | 6 | 4 | 4 |
| Duration (s) | 0.99 | 1.15 | 1.12 | 1.10 |
| Maximum Lag (s) | n/a | 0.060 | 0.035 | 0.015 |

## DISCUSSION

The FIR Hanning filter was chosen for this EOG filtering application because it minimizes lag and distortion of the eye movement duration. Minimizing lag is important to the performance of the system because the observer may notice a lag of greater than 1 ms. Also, the duration of the eye movement should be distorted as little as possible by the filter, since distortion could cause the prosthetic eye to oscillate in an attempt to track the undistorted movements of the natural eye. All the filters tested introduced lag, however this lag can be compensated by using a phase lead controller. The oscillatory effect of distorted duration can be compensated by adding damping to the controller. Future work will include compensating for DC drift in the EOG signal, designing the control system, and implementing a clinical model of the prosthesis.

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# SIDEWALK PERFORMANCE OF GPS FOR BLIND NAVIGATION

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## ABSTRACT

GPS was originally designed for open areas with few obstructions or reflections to degrade the satellite signals. The technology holds considerable promise as a source of navigational information for blind travelers, but there is little published data on its use in environments of interest to this population. We made observations in various urban locales with current GPS technologies. Results indicate that performance varies widely from the usually quoted figures, approaching these only in open, unobstructed areas. Proximity to buildings and other urban features degrades performance considerably. Combination of GPS with other inputs such as dead reckoning would provide a means of improving accuracy and coverage in real-world urban use.

## BACKGROUND

A number of researchers have proposed navigation systems for blind persons based on GPS technology, including Loomis (1993, 2001), the MoBIC (Mobility of Blind people Interacting with Computers) project (MoBIC Consortium, 1997), and Arkenstone Inc. (Fructerman, 1996). A derivative of the latter system is now commercially available in the form of GPS-Talk, manufactured by Sendero Inc of Davis, California. Many others have proposed similar systems, which clearly show promise in this application.

Commonly quoted figures regarding GPS errors, sometimes as low as one meter, are invariably based on ideal conditions, usually with external antennas set up in an open sky, low horizon location. A long sequence of measurements is usually made with a sample logged by computer every two seconds for days or weeks. The present paper attempts to explore achievable accuracy in environments of interest to blind travelers, who are often on the sidewalk adjacent to buildings, passing under trees, and encountering other conditions that may block the line-of-sight satellite signals or cause multipath transmission and reflections that confuse the receiver. The absence of published information on GPS use in the real-world, urban environments of interest to blind travelers, and the desire to explore incorporation of GPS inputs into future orientation systems for this population and those with multiple impairments, prompted us to conduct some experiments to help fill this information gap.

## METHODS

The work reported here was carried out using a Garmin GPS III Plus, a state-of-the-art 12 channel GPS receiver. The receiver's own internal antenna was used. (Wilson (2001) reported better performance for this model with the internal than with an external antenna). For differential GPS readings, a Garmin GBR 23 beacon receiver was used to pick up signals from the nearest Coast Guard DGPS transmitter, located approximately 4.5 miles away at Point Blunt on Angel Island in the San Francisco Bay. A series of GPS readings was taken in three locations in San Francisco, chosen to represent a variety of typical environments and satellite reception conditions encountered by a pedestrian:

1. On the sidewalk (near the curb) outside the Smith Kettlewell Institute, a four story building on Fillmore Street, in a commercial/shopping/residential area of the city.

2. On the sidewalk (near the curb) on 20th Avenue, a wide residential street of two-story houses.

3. In Alta Plaza Park, an open area with a relatively low horizon, well under 10 degrees when averaged over all directions.

To test variations over time, sets of 20 readings, each spread over an extended period, were taken for each location and for each experimental condition (with and without selective availability, with and without differential signals etc – seven sets of readings in all). At the Fillmore Street location, three sets of 20 readings were taken for the three conditions (with selective availability, without selective availability and with differential signals). Each of these sets was distributed over 2 to four weeks. Similarly, 20 readings for each condition (with and without differential signals) were taken at the 20th Avenue and Alta Plaza Park locations, with each set of readings spread over two to three days.

To analyze the results, we plotted X-Y scatter diagrams and calculated the size of a circle containing 90% of observed readings in each case.

## RESULTS

1. Shopping Area Sidewalk:

Conditions here were definitely not optimal for satellite reception, even though the experimenter was standing out near the curb on a wide sidewalk 13 feet away from the adjacent building. Prior to abolition of Selective Availability, 90% of readings fell within a circle of 200 meters diameter. Removal of Selective Availability reduced the 90% confidence limit to 74 meters diameter. Addition of the differential signal slightly improved the confidence limit to a 60 meter diameter. These results are summarized in Table 1.

2. Residential Area:

The residential location, with only moderate-sized buildings in the vicinity, yielded a 90% confidence circle diameter for unaided GPS of 22 meters (Table 1). When the differential signal was added, average deviation from the mean position reading was reduced from 8.2 to 6.4 meters, but the variability of the readings actually increased, expanding the confidence circle diameter to 32 meters.

**Table 1. 90% Confidence Circle Diameter (Meters)**

| | With Selective Availability | Without Selective Availability | With Differential Signal |
|---|---|---|---|
| Retail Area | 200 | 74 | 60 |
| Residential Area | | 22 | 32 |
| Park (Open Area) | | 22 | 16 |

3. Open Park Area:

This environment gave the best results of the three locations tested, due to the unobstructed view of the sky in all directions. The 90% confidence circle diameter was 22 meters with unaided GPS, and 16.4 meters with the addition of the differential signal. (Mean deviation from the average reading was 5.3 and 3.9 meters respectively).

## CONCLUSIONS

For use in blind orientation in urban environments, it is clearly difficult to achieve the GPS accuracies that are often quoted in other contexts, and supplementation by other technologies is obviously needed if indoor navigation is desired. However it is clear that in many world outdoor environments, GPS can offer the pedestrian enough information to tell him what block he is on and probably allow determination of location to within a few street addresses. The technology is likely to play a significant part in the future of wayfinding systems for blind and visually impaired persons.

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# USING SIMULATION TO PREDICT AND SOLVE DESIGN PROBLEM

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## ABSTRACT

A wireless phone simulation was created to facilitate the exploration of accessible interface strategies that can be applied to various telecommunication products. The simulation proved to be useful for predicting the design problems and solving them.

## INTRODUCTION

The simulation described in this paper was created to support a series of projects aimed at creating accessible interface strategies that can be applied to various telecommunication products. A wireless phone was selected as a telecommunication product to work with at this stage. At the current stage, the project focuses on exploring interface navigation strategies that would provide access to the information on the display and on the buttons for users who are visually impaired or people working in an environment that prevents them from using their vision to operate a wireless phone. One technique being explored is referred to as "Suspend Activation. [1]". The main idea of the suspend activation mode is that once this mode is activated, the user is allowed to press any button on the phone surface without causing it to do anything. In other words, normal button activation is suspended. In this mode, the text or image on any button the user presses appears on the phone's display screen in large print, while at the same time the name and function of the button are spoken aloud by the device. When the user hears or "sees" a button he is interested in, he can drop out of this mode and press the button to activate it. In this way, users who cannot see the buttons or display can get access to the information on the phone display and handle the phone smoothly.

A simulation was created to test the feasibility and effectiveness of the suspend activation idea. It may be impractical and expensive to refine this strategy on a real phone that may not be easily modifiable. However, it is also difficult for designers to iteratively assess designs and create detailed specifications using only their imagination and paper prototypes. A computer simulation provides a compromise solution. By creating a simulated model on computer and applying all the possible access strategies, the researchers can get more direct experience and better understanding of the advantage/disadvantage of these options. The simulation also allows the project team to demonstrate each design in an easy to comprehend manner, so individuals outside of the design team are able to quickly review the design and offer feedback. Another important contribution of the simulation is its usefulness in detecting design problems that might otherwise have been ignored. Some design problems should be addressed in the early stages of development because making changes later would require significant lot of work.

## PROBLEM DETECTION AND SOLUTION

Before deciding on a phone image for the simulation model, the button arrangements, functions and operations of commercial phones currently on the market were reviewed. Questions arose about the reasonableness and logic of some widely accepted design standards. For example, on many phones, the "No" button is used as the power button to turn on/off the phone. Is there a good explanation for selecting "No", not "Yes" for the power button? Is it rational to assume that a person who never uses wireless phone before would try the "No" button first when he wants to turn on the phone? It is true that there is a power sign on the "No" button. But can people with no previous wireless phone experience notice this tiny mark and recognize its meaning quickly? There is a widely accepted arrangement for the number pad on commercial phones, but the arrangement of function buttons varies across manufacturers and phones. How many function buttons should appear? What are the best locations for these buttons? Is one arrangement more logical than another? Similar questions arose about the logic of menu structures in current designs. What criteria do developers use for determining menu order, frequency of use, intuitiveness or some other factor? Which words should be used in the top menu level to indicate the content of the submenu clearly and direct users to the desired function? These problems may look insignificant, but they are actually important since people usually explore the operation of a new product based on their previous experiences and it is important for designs to allow users to take advantage of this experience. It is also critical not to make arbitrary assumptions about users' habits. Proper solutions that meet the users' expectations will help them easily master phone usage. During the simulation process the design team met regularly, to address the questions mentioned above and to discuss the advantage and disadvantage of each possible choice. Several models were created adopting different strategies for evaluating and improving the design.

The simulation can be used to detect whether the accessible solutions is feasible or not. For example, there are several possible techniques for applying the suspend activation concept on a wireless phone. When a simulated model with elementary functions such as call history and address book is created, it is easy to test the feasibility and benefits of these options by implementing them on the model and trying them. The options considered for initiating suspend activation mode included adding an extra key or adopting an existing button. The latter method, which is also called key take over, is preferred because no change in button layout is required. In addition, the cost of this strategy may be lower since only software modification is needed. However, each of the existing buttons on a phone has its own function, no matter how important or negligible. The question becomes, is it possible to "take over" an existing key without influencing the other functions? How to deal with the original function of the selected button? Is the method used to initiate the suspend activation mode easily discoverable? During the repetitive tests on the simulation and in discussions, the design team found it is possible to implement the suspend activation mode using a key takeover approach. Buttons which are not normally used alone in standby mode can be used to initiate the suspend activation mode. For example, in the current simulation if the "*" is entered followed by "Yes", normal operation is suspended and users can explore the phone display and functions by just listening.

The main goal at the current stage is to provide visually impaired users the ability to identify the name and function of the buttons by showing the text/image of a button on the screen in large print and voicing the displayed content at the same time. The descriptions of the buttons functions are layered with increasing levels of detail. Each button press presents the user with more detailed information. (See Figure1) Using the simulation, the researchers can get feedback on whether the voice instructions are consistent and understandable and how they might be improved.

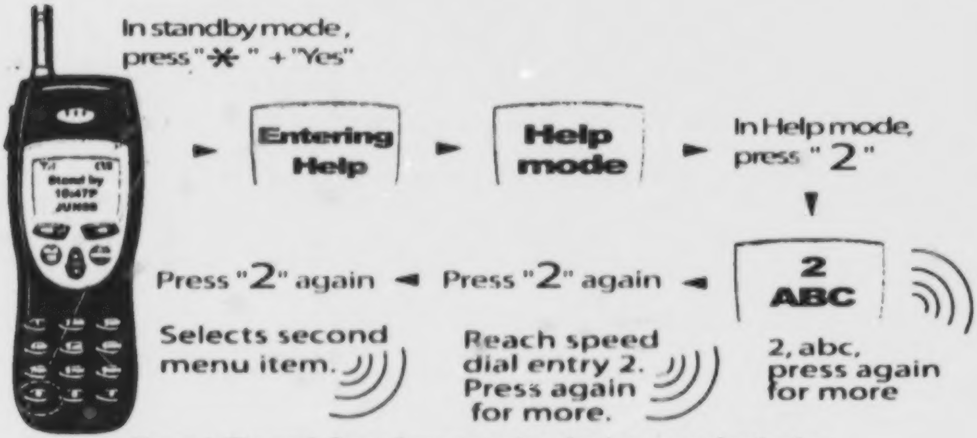

Figure 1. The work flow of one strategies adopting suspend activation

Since the simulation is just used to explore disability access issues related to phone operation, the model is somewhat different from a full prototype and it is not fully operable in some aspects. Likewise, the design error/problem predicted by simulation would be different from those detected in user test. For example, the simulation is operated on the computer screen by keyboard or mouse, so the difference between mouse/keyboard click and finger press might affect the final design of the accessible strategies.

## FUTURE WORK

There are still many restraints on the simulation. It is not as fully operable as a real product and it cannot be used for usability testing. The current target population for this project is people with vision impairments. In the future we plan to expand the research scope to include users with other disabilities and apply these features on other electronic devices.

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# AN INTELLIGENT COGNITIVE ORTHOSIS FOR PERSONS WITH MODERATE-TO-SEVERE DEMENTIA: RESULTS AND RECOMMENDATIONS

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## ABSTRACT

The COACH is a prototype of an intelligent computerized device that was developed to assist people with dementia complete ADLs with less dependence on a caregiver. It was tested with 9 subjects with moderate-to-severe dementia during handwashing in a study lasting 60 days. These trials showed that individual changes in the number of handwashing steps completed without assistance from the caregiver increased by 10 to 45 percent when the device was present.

## INTRODUCTION

Dementia reduces a person's ability to perform activities of daily living (ADL) because of the inability to remember the proper sequence of events that must occur. The current solution is to have a caregiver continually provide verbal reminders. However, this dependence is difficult to accept and often contributes to anger or helplessness. An intelligent computerized device that provides reminders and monitors progress may reduce dependence on a caregiver and enhance the perception of dignity and privacy.

## BACKGROUND

Work in the area of cognitive orthotics has included the development of several devices and software programs. Researchers including Kirsch, Levine, Lajiness-O'Neill, & Schneider (1992), Cavalier & Ferretti (1993), and LoPresti, Friedman, & Hages (1997) developed prototypes of computerized devices, and showed that subjects with brain injury and learning disabilities were able to complete various vocational and ADL tasks with more independence when the devices were used. The results from these, and other efficacy studies have been described in more detail in other publications by the authors, Mihailidis, Fernie, & Barbenel (2001).

The majority of these devices relied on input from the user for feedback (e.g. pushing "OK" after a task}. Such an action may be achievable with persons who have less severe cognitive impairments, but is less likely to be completed by persons with moderate or severe levels of dementia because they lack the required planning and initiation skills. As well, these devices required manual re-programming in order to be adapted for a particular user. Again, this cannot be expected from a person with dementia, or from his or her caregiver. A device is needed that can be automatically customized for a user through its own algorithms based on the user's performance. The COACH, which is described in a previous paper by the authors Mihailidis et al. (2001), is a first prototype of such a device.

## DESCRIPTION OF THE DEVICE (THE COACH)

A video camera and a tracking bracelet were used to find the two-dimensional (x and y) coordinates of a user's hand. These coordinates were used to determine which step in a handwashing task the user was completing. If the user changed the sequence of the steps but could still reach the final goal, the program adapted itself to guide the user through the new sequence of steps. If a match could not be found, the program predicted which step the user should be performing and played a pre-recorded verbal prompt over speakers inside the environment. If necessary, the device repeated the cue after an interval. The next issued cue had more description with respect to how to complete the step, such as location or colour of an object, or addressing the user by name. If the user did not respond to any of the cues issued, the device stopped and called for a caregiver to give assistance. The device was installed in a test washroom in long term care at Sunnybrook & Women's College Health Sciences Centre.

## EFFICACY STUDY

### Objective

The objective was to determine if a subject can complete handwashing with less dependence on a caregiver when using the COACH, and how well the COACH and its algorithms executed the functions that they were designed to perform.

### Method

A withdrawal type ABAB single-subject research design (SSRD) was completed with nine subjects who had moderate-to-severe dementia. Four test phases were completed: two baseline phases ($A_1$ and $A_2$) and two intervention phases ($B_1$ and $B_2$). For each of these phases three primary target behaviours were observed:

1) The number of steps in the handwashing task that a subject completed without any interaction with a human caregiver;
2) The number of interactions the caregiver had with the subject; and
3) The subject's functional assessment scores (FAS), which was based on the Functional Independence Measure (FIM™) tool.

The baseline phases ($A_1$ and $A_2$) measured these target behaviours without the effects of the computerized device. The intervention phases ($B_1$ and $B_2$) measured these target behaviours in response to the device providing assistance instead of the human caregiver. Each subject completed all four phases. One trial per subject was conducted every day of the week, except for Saturday and Sundays, for 60 days. A volunteer, who had previous experience in caring for people with dementia, acted as the caregiver for all of the subjects during these trials.

### Results

The subjects' levels of dependence on the caregiver decreased when the device was introduced, and then increased when the device was removed. Individual improvements in the number of handwashing steps that were completed without assistance from a caregiver ranged from approximately 10 percent to 45 percent. This pattern was replicated in the data collected for the other target behaviours observed—i.e. the number of interactions required between the caregiver and subjects decreased and the subjects' FAS scores increased during the intervention phases. Group data was analyzed using a Repeated Measures ANOVA to corroborate the findings from the visual analysis of the data. The changes observed in the subjects' target behaviours were found to be statistically significant ($p < 0.01$).

The COACH assisted the subjects with approximately one-third of the steps that they were able to complete without assistance from a caregiver during the two intervention phases. The number of misses and false alarms was relatively low over both phases, which resulted in relatively low error rates (approximately 3 percent error). The mean response time of the device was 1.7 seconds ($\sigma = 0.7$), compared to the mean response time of the caregiver which was 3.2 seconds ($\sigma = 1.7$).

## DISCUSSION

The efficacy study has shown that the COACH was effective in assisting the subjects who participated. The number of handwashing steps that each subject was able to complete without a caregiver improved whenever the device was used, and the number of interactions required with the caregiver decreased. However, the study has also clarified specific improvements that are required in future devices, and several important questions to be answered during a future research phase.

## RECOMMENDATIONS

The following are recommendations for the design of future devices:

- An improved tracking system is required which: a) provides a faster sampling rate so that quick actions are not missed; b) reduces loss of data due to occlusion of the hand from the view of the camera; and c) reduces ambiguities by including the third dimension and gesture recognition.
- Intelligent algorithms for training the device should be developed, which include the device automatically learning which sequences of steps are acceptable.
- Better cueing strategies should be developed and implemented. Visual cueing should be used in addition to verbal cues, such as displaying an image of the caregiver demonstrating a step.
- The device should be able to respond to verbal questions by the user such as "where" and "what".

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# ROBOT USE AND COGNITIVE DEVELOPMENT IN CHILDREN WITH CEREBRAL PALSY

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## ABSTRACT

A small robotic arm has been used to provide augmented manipulation for children who have severe physical disabilities. A three-step task controlled by single switches allows the children to participate in educational and play-related tasks. The robotic system is located in community school setting where the children use it over a four-week period (10-12 sessions). Evaluation using goal attainment scaling has shown that the majority of the 10 children in the study have exceeded the expected outcome in understanding of the robot, functional use and carry over to the classroom. Teacher interviews have revealed a very positive reaction to the use of the robot in the school and other effects such as increased vocalizations, greater interest in classroom activities and a high degree of interest in using the robotic system.

## BACKGROUND

Children with severe motor disabilities cannot exert control their environment, and they have few opportunities for independent exploration. As a result of this passivity, these children may remain dependent and socially inactive unless they are given active opportunities to explore their surroundings by alternative methods [1]. Interaction with the environment through play can overcome this passivity. Play allows development of environmental exploration. As Pierce [2] states, it is through play that "the child learns to explore, develop, and master physical and social skills". The purpose of this paper is to describe the use of a robot arm system by children with severe disabilities. The robot arm use was intended to facilitate learning through a structured play-based routine.

## RESEARCH QUESTIONS

1.How do children with severe physical disabilities physically control a robotic arm to engage in educationally related play tasks?

2. What is the impact of the use of a robotic arm on children's behaviour, social and academic performance?

## METHOD

The experimental set-up consists of: a Rhino Robotics XR-4 5-degree of freedom robot with Mark IV controller, a Toshiba P-90 laptop computer running a custom control program, and a large tub of dry macaroni in which objects could be buried and retrieved by the robot arm movements of scooping and dumping. The robot arm can rotate about its base, bend (flex/extend) at the shoulder, elbow and wrist, rotate at the wrist and. open and close its two-fingered gripper. Each of the motors on the robot has an encoder, which provides feedback to the robot controller regarding the position of each motor. The digital inputs on the Mark IV controller were used to interface the child's switches to the controller. The child uses these switches to control the robot. The robotic arm was programmed to carry out tasks when the child pressed one to three switches in a sequence. Ten children who had severe physical disabilities participated in this study. Their ages ranged from 5 to 12 years old. The functional anatomical sites used by the children for switch control included head, hand, elbow and foot movement. The children were unable to engage in play or educational activities independently or with other children or adults. The robot was located at the school site of the participating child. Three to four 30 to 45 minute sessions were held with the child each week for a period of four weeks. Thus, each child had 10-12 sessions. This gave us the opportunity to evaluate learning as well as discovery and possible satiation by the child. The teacher and/or aides were interviewed at the end of the four-week period.

Three tasks were used: (1) the arm dumped macaroni from a glass using one switch-hit. The adult filled the cup with macaroni (by hand). The child hit a switch causing the robot arm to dump the macaroni. (2) The child used two switches to first dig an object out of the macaroni, and then dump the macaroni and object. The adult buried the object and caught it when the child dumped it, and (3): The child used three switches to initially position the robot arm for digging, then scoop or dig an object out of the macaroni, and finally dump the macaroni and object. The scooping or digging movement required from one to 8 repeated switch hits to complete. Each child's session using the robotic arm was video taped for later analysis. Goal Attainment Scaling (GAS) was used to answer the first research question. GAS is a criterion referenced, individualized measure of the impact of an intervention [3]. The advantage of GAS is that it allows multiple and individualized goals to be developed for each child.

## RESULTS

For this project we developed individualized goals for each child in three categories: (1) operation of the robot, (2) functional task describing interaction, (3) carryover to the classroom. Examples goals for one child who had only head (left and right) movement and unknown cognitive skills are shown in this table:

| Score | Operational Scale | Functional Scale | Classroom Carryover Scale |
|---|---|---|---|
| +2 | Controls 2 switches, 4 step scoop | Anticipates play outcome of robot use | Unexpected gains in classroom goals |
| +1 | Controls 2 switches, 2 step scoop | Initiates turn and anticipates result | Shows increased classroom enjoyment |
| 0 (expected level) | Controls 2 switches intentionally | Understands "It's your turn", responds appropriately | Shows more interest (more vocalizations, greater attention)) |
| -1 | Controls 2 switches, w/prompting | Understands turn taking with prompt ("hit your switch") | Anticipation of robot activity |
| -2 | Controls 1 switch intentionally | Doesn't understand turn taking | No anticipation of robot activity |

T values were calculated pre and post robotic use for each child [3].

$T=50+(10\Sigma x_i)/\sqrt{(1-\rho)\Sigma w_i^2+\rho\,(\Sigma w_i^2)}$; where: $x_i$=outcome score (-2 to +2), $\rho$=30 (a constant reflecting the estimated inter-correlation for scores on multiple goals). A T score of 50 corresponds to the expected outcome, the 0 point on the original scale. Pre-robotic session T scores were below 50 for all children. The majority of the children in the study had T scores greater than 50 on all scales after using the robotic arm for a period of approximately four weeks. The greatest improvement was in operational scale scores, followed by functional scale and carryover scale scores, respectively.

In order to answer the second research question, (determination of the impact of the use of a robotic arm on children's behaviour, social and academic performance) we used a series of open-ended questions for the teacher to establish the perceived difference in the child after interaction with the robotic system and to provide insight into the child's social and academic performance before and after using the robot. This also approach also contributed to the scoring of the carryover scale of the GAS. Qualitative analysis of the interview responses was conducted to determine themes in the overall responses. In general, teachers noticed differences in overall responsiveness, amount of vocalization and interest (i.e., greater attention to tasks, or longer attention periods) for children who used the robotic arm. All teachers reported that the students enjoyed using the arm and looked forward to the periods when they were able to use the robot.

## DISCUSSION

The results reported here are an extension of an earlier study in which children used a robot in a laboratory session over a limited number of sessions [4]. By locating the robot in the community school setting we had the opportunity to study learning by the children over time as well as to investigate secondary results that occurred in the classroom as a result of the use of the robotic arm. The skill with which the children controlled the robot increased over the four-week period, and there was little or no satiation. The major reason for this was that we used large plastic eggs for the digging/dumping task. By hiding different objects in the egg, we could vary the task and match it to the child's ability level. One child used letters hidden in the egg to spell her name and label other objects. Each letter was in the egg. The child used the robot to dig in the macaroni for the egg and to present it to the adult who asked her to indicate where the letter was to be placed to spell the desired word. In other cases the child was asked to sort objects found in the egg (e.g. colours, shapes, similar objects like animals or cars). Using these approaches, we found that significant learning by the children did occur and that there were noticeable effects in their overall behaviour and classroom performance during and after their use of the robotic arm system.

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# *ENABLING TECHNOLOGIES FOR PEOPLE WITH DEMENTIA*

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## ABSTRACT

The Enabling Technologies for People with Dementia (ENABLE) project is concerned with development and adaptation of technological products which people with dementia can use to carry out daily tasks which they previously were unable to do, due to their disease. The objectives of ENABLE are to develop prototypes and provide test series of enabling technological products; to develop methodology for assessment of effects of using the products; and to examine whether the products can enable people with dementia living in their own home. People with dementia will test the products in their own homes, and effects of using them will be assessed through interviews with the users and their carers. Mitigation or solving problems for people with dementia, enhanced self-esteem and well-being as well as costs and benefits at individual and society level will be observed. The quality and effectiveness of the products will also be examined.

## BACKGROUND

Due to the increasing longevity of the general population, the prediction that the prevalence of dementia will grow is now undisputed. Dementia is expected to reach epidemic proportions on a global scale by 2020. As carers of people with dementia must provide increasing levels of care as the disease progresses, they often experience many difficulties in finding sufficient time to care, especially given carers increasing participation in the labour market. Indeed, fewer people are now taking on the role of carer and this trend will place the care responsibility upon public and private care structures that have not planned for these imminent demands. Of those people who do opt to take care of their relative, many experience difficulties dealing with the cognitive, behavioural and physical, problems of their relatives. This further jeopardises the availability of carers as coping with these difficulties places the carer themselves at risk of health problems such as depression, stress and anxiety.

People with dementia, like many older people, want to continue to live at home independently for as long as possible and to manage the daily tasks that this involves. However, the abilities of people with dementia to handle these tasks deteriorates progressively and often rapidly, which may lead to an overall reduction in independent living. Even at the early stages of the disease people with dementia experience frequent failures in carrying out daily tasks.

## RESEARCH QUESTION

The main objective of this study is to improve the quality of life of people with dementia and their carers. This will be done by assessing whether enabling products can alleviate or solve certain practical difficulties experienced by people with dementia and their carers in carrying out daily tasks for people with dementia living in their own home. The project has set itself several other key scientific and technological objectives as follows:

- Develop a test series of products that aim to enable the person with dementia to keep him/herself occupied with activities which give pleasure, support memory or facilitate communication, and to validate products that are commercially available.
- Develop a methodology for assessment and analysis of effects of products aimed to enable people with dementia living in their own home.
- Develop an approach towards cost/benefit analysis and make preliminary estimations based on the experience of users and carers.
- Examine whether such products can enable people with dementia and support their wellbeing by giving positive experiences, reducing worries and unrest, and reducing the burden on carers.
- Disseminate knowledge to people with dementia, their carers and organisations as well as to health and social care service systems and industry about the potential of enabling products.
- Make an overview of problems and needs which each of the products aim to solve or reduce both for the person with dementia, for their carers and for society.

These objectives may seem paradoxical since technology is often associated with making people feel incompetent because they may lack the capability to interact with it. ENABLE wants to demonstrate that technology does not have to be disabling for people with dementia and that modern technology can close the gap between the skills required to use technology and the person's abilities.

## APPROACH

To achieve the objectives outlined above, ENABLE enforces product development and design that is user led. The specific needs of people with dementia have been prioritised in ENABLE and these have been identified from the literature (1), previous projects (e.g., TED and ASTRID), and from focus groups held with family carers and professionals within ENABLE. Studies have shown that access to appropriate technological products can reduce some of the activity limitations that restrict social interaction and the participation of people with dementia in daily life (2) (3) (4) (5). Specifically, ENABLE is developing products that aim to facilitate independent living, support memory, assist communication, and provide occupation and stimulation, as follows:

Table 1: Products being developed in the ENABLE Project

| Item | Function | Effect |
|---|---|---|
| Automatic night and day calendar (Forget-me-not$^{TM}$ adaptation) | Day, date and whether it is morning, afternoon, evening or night is displayed. | Supports memory and facilitates time orientation, e.g., may avert people from leaving home during night, etc. |
| Locator for lost objects | Pressing picture button causes lost item to bleep. Stops when item is located. | Find frequently lost items, e.g., keys, purse, etc. Reduces worry and facilitates independent living. |
| Automatic bedroom lamp | Turns on the light automatically when the person gets out of bed. | Facilitates independent living. Prevent falls at night. Reduces anxiety. |
| Bath water level monitor | Automatically turns off bath/sink taps if water reaches a certain level. | Facilitates independent living. Increases safety. Reduces worry. |
| Cooker usage monitor | Monitors thermal environment on gas cooker hob, turns off and resets knobs when dangerous levels are detected. | Facilitates independent living. Enables the safe use of the gas cooker. Reduces worry. |
| Remote day planner | A computer screen which displays | Facilitates independent living. |

| | | |
|---|---|---|
| | tasks and activities for the day as input by carer via the internet. | Reduces worry of not knowing appointments / events of the day. |
| Picturegramophone | Listen to favourite songs and singers, by touching a screen connected to PC. | Provides occupation and stimulates activity and memories. |

ENABLE is unique in its endeavour to develop a methodology to assess how technology can facilitate independent living with people with dementia. In order to make appropriate choices in this area, information about existing methods is being gathered, especially knowledge about the performance of these methods, their strengths and weaknesses. State-of-the-art reviews are being prepared on ethical aspects, diagnosis and severity of dementia, and assessment of functional abilities. The study also intends to examine whether the alleviation or solution of these difficulties may have further impact on supporting independent living and the wellbeing of the person with dementia and reduce the burden on the carers. Finally, the study will also assess whether the products used yield any socio-economic costs and benefits. The effects of using the developed products will be evaluated at regular intervals in Ireland, England, Norway and Finland. People with dementia and their carers who consent to participate in the study will be given one ENABLE product. Users will be assessed to ensure that the technology provided matches their needs appropriately. Results from the assessments will be available in 2003 when the project terminates.

## DISCUSSION

Given our increasingly ageing population and reduced availability of family carers, there is an urgent need to ensure that current advances in technology do not ignore the possibilities and benefits they can provide to people with dementia and their carers. There is also a need to motivate innovators and technology developers to collaborate with people with dementia, carers, and health care workers in this new and exciting field. Results from this research study will provide a better understanding of how such barriers can be removed, so that ultimately people with dementia can live in dignity and continue meaningful participation in life.

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## ACKNOWLEDGEMENTS

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# DEVELOPMENT OF THE GAME$^{CYCLE}$ EXERCISE SYSTEM

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## ABSTRACT

The GAME$^{Cycle}$ exercise system can help people with spinal cord injury (SCI) increase their physical activity level, as well as improve their cardiovascular fitness. An arm-ergometer is placed on a turnstile to allow steering in much the same way as an arm-cycle. One optical encoder on the sprocket of the arm-ergometer is used to sense the speed, and another one on the turnstile is used to sense the direction. Both the speed and direction signals are sent to a PC game port to play the video games.

## INTRODUCTION

The activity level of people tends to decrease after a spinal cord injury. Research shows that daily wheelchair propulsion activity level of an individual with a spinal cord injury is not sufficient to maintain or improve their cardiovascular fitness level [1]. Also research show that sedentary individual with paraplegia have low maximal oxygen consumption, and most of them are less fit than either physically active counterparts or the sedentary unimpaired population. Because of the sedentary lifestyle and lower rate of maximum oxygen consumption, cardiovascular diseases are an increasing health concern for wheelchair users.

A regular exercise program might not be available or might be too difficult to participate in either physically or psychologically. Many individuals who use wheelchairs have additional functional limitations with their cardio-respiratory systems, which might decrease their desire or ability to exercise. The exercise system like the standard arm-crank or roller systems can be boring and little motivation is provided to maintain the exercise program. Some research has shown that the video-game-play has increased metabolic levels and heart rate, while other research reported considerably increase systolic blood pressure and significantly increase heart rate in young men during video-game-play [2-4]. This increase is similar to mild-intensity exercise.

## METHODS

GAME$^{Cycle}$ consists of mechanical parts, interface circuit, and one PC, see figure 1. The mechanical parts consist of arm-ergometer, pedestal, crank and pinion. The arm-ergometer is connected to an optical encoder which controls the Y-axis (up/down) on the screen of a PC monitor.

There is a nylon strap wrapped around the ergometer fly-wheel that increases/decreases tension on the fly-wheel. The arm-ergometer is affixed to the horizontal beam with a pivot. This rotation controls the X-axis (right/left) movement on the screen.

Interface circuit consists of one micro-controller MC68HC11, two optical encoders, and two digital potentiometers. See figure 2.

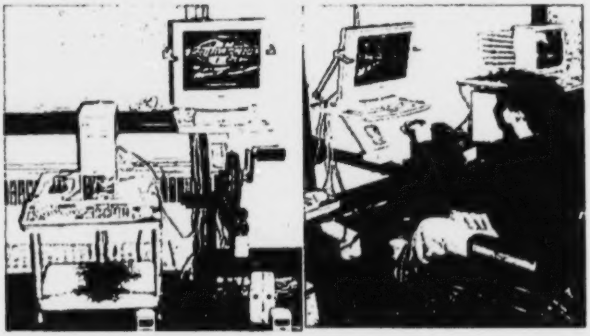

Figure 1. GAME$^{Cycle}$ exercise system

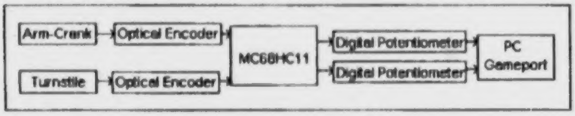
Arm-Crank
Optical Encoder
Turnstile
Optical Encoder
MC68HC11
Digital Potentiometer
Digital Potentiometer
PC Gameport

Figure 2. Diagram of GAME$^{Cycle}$ interface circuit

The optical encoder HEDS-5700 series are low cost, high performance, optical incremental encoders with mounted shafts and bushings. It contains a collimated LED light source and special detector circuits, which allows for high resolution, excellent encoding performance, long rotational life, and increased reliability. The unit outputs two digital waveforms which are 90 degrees out of phase to provide position and direction information. Its resolution is up to 512 cycles per revolution. Two channels TTL output and single 5v supply. One HEDS-5700 series optical encoder is mounted on turnstile to sense the steering signal. Another encoder is mounted on the sprocket of the arm-ergometer to sense the speed signal. When making a left turn, both the encoder channel A, and channel B will send out a pulse. These two signals are sent to micro-controller to detect whether to make a right turn or left turn, see figure 3. If you make a right turn, the pulse of channel A will lead the pulse of channel B. Otherwise the pulse of channel B will lead the pulse of channel B. Same idea is used in speed signal. Two digital potentiometers are connected to game port of PC as speed, and direction signals.

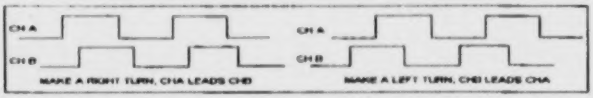
CH A
CH B
MAKE A RIGHT TURN, CHA LEADS CHB
CH A
CH B
MAKE A LEFT TURN, CHB LEADS CHA

Figure 3. Optical encoder CH A, CHB output signals when make a turn

System software was programmed in Motorola assembly language. It consists of three parts. See Figure 4. One is for the system initialization, and two interrupt services. When power the computer, the system initialization will drive the two digital potentiometers to the center position. One interrupt service is used for counting the fly-wheel speed. The faster the fly-wheel rotates, the more

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pulses will be sent to digital potentiometer. The wiper of digital potentiometer will be moved according to the speed of fly-wheel. Another interrupt service is used to count the horizontal beam rotation. This rotation will generate the direction signal of the PC screen.

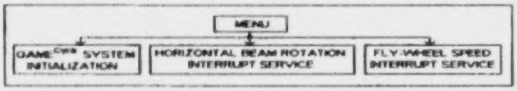
MENU
GAME$^{\text{Cycle}}$ SYSTEM INITIALIZATION
HORIZONTAL BEAM ROTATION INTERRUPT SERVICE
FLY-WHEEL SPEED INTERRUPT SERVICE

Figure 4. Diagram of GAME$^{\text{Cycle}}$ system software

## RESULTS & DISCUSSION

The activity level of people tends to decrease after a spinal cord injury. A regular exercise program might not be available or might be too difficult to participate for these people. The purpose we developed the system is to help individual with a spinal cord injury increase their activity level, and maximal oxygen consumption. We put two optical encoders in the exercise system. One is on the sprocket of the arm-ergometer to sense the arm-crank speed. Another is on the turnstile to sense direction. The system is easy to store in most homes or physical therapy gyms. Our preliminary research shows that GAME$^{\text{Cycle}}$ system can increase individual's metabolic level and heart rate. A questionnaire was conducted to 11 subjects with spinal cord injury after using this system. See table 1. From this table, we found GAME$^{\text{Cycle}}$ system would help motivate individual with spinal cord injury to exercise on a regular basis.

TABLE1 QUESTIONNAIRE ABOUT GAME$^{\text{Cycle}}$ SYSTEM

| Question | Yes | No |
|---|---|---|
| Do think GAME$^{\text{Cycle}}$ system would help motivate you to exercise on a regular basis (more than once a week)? | 8 | 3 |
| Do you think GAME$^{\text{Cycle}}$ system would help to motivate you to workout longer and/or more often? | 8 | 3 |
| Do you think the GAMECycle system would help motivate individual that use manual wheelchairs to exercise on a regular basis? | 11 | 0 |
| If this piece of equipment were already available, would you purchase? | 8 | 3 |
| Overall, did you have fun playing with GAME$^{\text{Cycle}}$ system? | 9 | 2 |
| Overall, was the GAME$^{\text{Cycle}}$ system easy to operate? | 9 | 2 |

## ACKNOWLEDGMENTS

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## Stretch and Exercise Station

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### ABSTRACT

Our client, a nine-year old girl, has a form of cerebral palsy that affects only her legs and causes spasms and stiffness. The goal of this project was to provide her with a stretch and exercise machine that would improve her strength and flexibility, and thereby aid in her self-sufficiency. This was accomplished by modifying an existing weight bench to meet our client's specific needs. The completed station provides four exercises, and can be used daily with only minimal assistance from an adult caregiver.

### BACKGROUND

Our client has a specific form of cerebral palsy called spastic diplegia [1]. Both of her legs are affected by spasms and stiffness. She cannot walk without assistance, such as canes or crutches. Two interventions are currently used to address these issues. First, targeted Botox injections are used to decrease muscle spasticity. Physical therapy that focuses on stretches and exercises of the leg is also employed.

Both interventions have limitations. Botox injections last for approximately four to six months and must be re-administered. Our client's physical therapist makes weekly visits to assist with stretches and exercises; however, these activities could yield a higher benefit if performed daily.

### PROBLEM STATEMENT

The goal of this design project is to provide our client with a stretch and exercise machine that will enable her to become stronger and more flexible and aid in her self-sufficiency. Four main objectives must be met for this goal to be accomplished. Two passive stretches must be supported: a hamstring stretch and an abductor stretch. Two active exercises must also be supported: a quadriceps extension and a hip raise. These specific activities were selected in consultation with our client's physical therapist.

### RATIONALE

This is a specialized device. This is necessary to provide our client with a means to exercise without the supervision of a physical therapist. The device will also allow our client to improve flexibility and strength in her lower extremities.

### DESIGN AND DEVELOPMENT

We followed a common process for engineering design. Requirements were gathered by meeting with both our client and her physical therapist to clarify the need. This phase was also used to understand how the physical therapist performed the stretches and exercises with our client. Initial physical measurements of our client were taken for the next design phase. After we developed a goal statement along with objectives and constraints, alternative solutions were considered by creative brainstorming and discussion. After evaluating the feasibility of each design alternative, we decided to modify an existing weight bench to meet our client's needs. This decision would meet all of our top-priority constraints: safety, adjustability, versatility, portability, and durability.

By utilizing block diagrams, mechanical sketches, and researching available commercial equipment, we made a preliminary design. This design was based on modifying an existing weight bench to our client's needs. As each requirement and objective became more focused, through ongoing meetings with our client and her physical therapist, we refined and detailed each objective's design. This refinement process, including client testing, allowed the team to design and develop a device that meets all objectives (see Figure 1).

Figure 1 - Completed Station

Specifically, we modified the factory lat tower to a 90° angle with a ratcheted leg lifting mechanism to support the hamstring stretch. The pulley system provides a 2:1 mechanical advantage and allows our client to easily raise her leg to a secure position. As shown in Figure 1, safety bars were added to both sides of the bench seat. These bars allow our client to easily traverse the length of the bench without involving her legs. The bars also act as handholds during exercise and help with mounting and dismounting from the bench seat. An abductor wedge was designed for placement between our client's legs during the abductor stretch (see Figure 2). This wedge positions her legs at an appropriate angle for maximizing the benefits of the stretch. A mounting bracket was placed on the bottom of the wedge so that it can be mounted on the vertical lat tower bar acting as a cushion to prevent our client from accidentally bumping her head on the bar. The original arm curl support was modified to serve as an "incentive tray." By learning our client's hobbies and interests, we incorporated her interest in music as an incentive to use this device. The incentive tray will hold any item with the use of industrial Velcro and guide pins. We provided a small electric piano as her first incentive to use during the abductor stretch and leg exercises (see Figure 3).

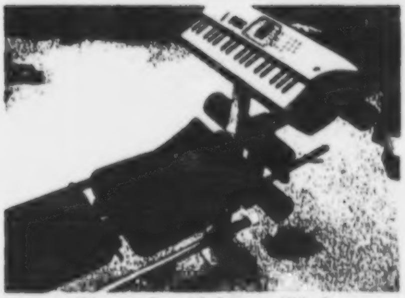

Figure 2 - Abductor Wedge

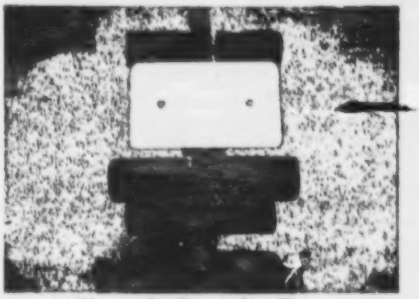

Figure 3 - Incentive Tray

In addition to the above modifications, we made several modifications beyond our original objectives. The leg exercise L-bar, seen partially in Figure 2, was modified with additional position holes. These holes allow the foam support pad bars to be placed in multiple configurations allowing the device to grow as our client grows. We also added a quick release pin so the L-bar can easily be removed when not in use. A movement wheel was added at the base of the lat tower so the bench can be moved easily. We also placed industrial felt pads on the bench bases to protect the wooden floors in our client's home.

## EVALUATION

The device has been continually evaluated using the team's most valuable resources: our client and her physical therapist. During the initial design phase, the preliminary design was reviewed with the physical therapist and refined based on her expert advice. Following each development step, the device was transported to our client's home for evaluation and testing while the physical therapist provided additional input. These meetings were invaluable because they allowed us to perform real-time tests, measurements, and to consider unforeseen complications. The modified bench lat tower, now the device's hamstring stretch system, was the most complex. This complexity required more detailed mechanical design and quantitative analysis of stress and strains.

## DISCUSSION AND CONCLUSIONS

The device meets the intended goal and all objectives. The device is safe, adjustable, durable, and easy to use. The device will easily fit through standard doorways; however, the device is heavier and less portable than originally intended. We placed a great deal of focus on the professional appearance and aesthetics of the device.

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## ACKNOWLEDGEMENTS

The design team would like to acknowledge the expert advice of our client's physical therapist, Ms. Barbara Howard. We would also like to acknowledge Mr. Joe Owen for his machining help. We would like to thank our professor, Dr. Larry Bohs, for his guidance throughout the entire project.

# Momentum: A Novel Hand-Powered Cycle

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## Abstract

A novel hand-powered cycle, *Momentum,* has been designed and built. The cycle is powered by the rider providing a vertical, reciprocating motion similar to that used in transferring to-and-from a wheelchair. Steering, braking, and gear shifting can all be accomplished without the rider removing their hands from the handlebars. More detailed information about this cycle can be found at: http://www.engr.wisc.edu/me/faculty/fronczak_frank.html

## Introduction:

Currently in the United States, approximately 70,500 people have paraplegia as the result of spinal cord injuries. Amputations involving the lower limbs number well over 280,000 (1). These figures represent an ever-growing population with unique physical needs. While spinal cord injuries and amputations may prohibit their participation in some sports using traditional equipment, disabled individuals can turn to alternative sports or the many commercially available pieces of equipment adapted to fit their requirements.

The first such alternative sport to gain widespread acceptance, wheelchair racing, was introduced to the United States in 1956. Initially, the sport required all athletes to use the same equipment. (2) These rules evolved to allow modified wheelchairs in order to better accommodate individuals' strengths and preferences. This opene~~d the door~~ to a revolution in the design of sport and racing wheelchairs. Gradually, in response to an increased interest among disabled athletes for higher speeds and longer distances, hand powered cycles began to appear in the mid-1980's, with initial designs being simple modifications to sport wheelchairs. These evolved into the most common type of hand-powered cycles which are driven by a circular hand motion in a vertical plane, mimicking traditional bicycle pedaling. This motion, however, has several characteristics which limit the usefulness of these cycles. An alternative cycle design, which incorporates a novel means of providing propulsion, has been designed and built. This concept app[redacted]veral distinct advantages over the prevalent existing designs.

## Background and Objectives:

Several commercial models of hand-powered cycles are available for paraplegics and lower limb amputees. These products can be generally grouped by the type of motion used, most commonly, circular cranking in a vertical plane, or alternatively, reciprocating arm motion in a horizontal plane. Hand-cranking does not utilize a natural motion, and the muscles it uses are relatively small. Incorporating reciprocating motion typically results in heavier cycles and also limits the availability of gear ratios.

To overcome these limitations and thus expand opportunities for disabled individuals in recreational sports, a new cycle design with a radically different propulsion system has been developed. This cycle was developed by an interdisciplinary team of two mechanical engineers, a physical therapist, an exercise physiologist, and three disabled athletes (one T4 and two T12 paraplegics). The goal of the team was to design a cycle with a more effective propulsion system and that would allow the rider to steer, brake, and shift gears without interrupting the power stroke, and to do so with an intuitive and easy to use system. It was also essential that the final design be practical, affordable, and take into account concerns such as manufacturing, assembly, and maintenance issues.

This effort resulted in the design of a hand-powered cycle which utilizes a vertical, reciprocating, arm-stroke to provide propulsion power. This motion is similar to that used to propel wheelchairs and to transfer oneself to and from wheelchairs. The first cycle that incorporated this motion is shown in Fig. 1. Subsequent design and development activity led to the construction of a second cycle, shown in Fig. 2.

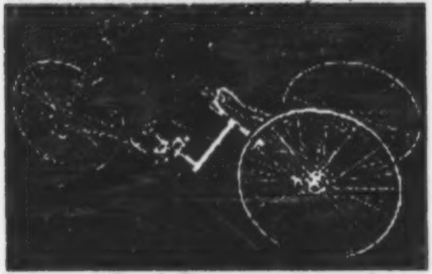

*Fig. 1: First generation cycle*

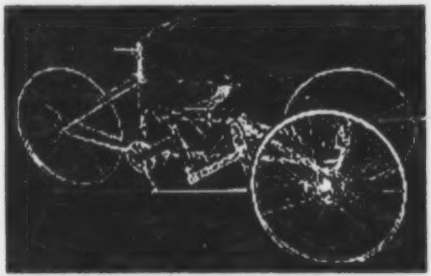

*Fig. 2: Second generation cycle*

**Overview of Cycle Design:**

The rider powers, steers, brakes, and shifts gears through the cycle's handlebars, allowing the rider's experience to be less like using a wheelchair and more like a riding a bicycle. To the extent possible, the cycle uses standard bicycle components to improve the robustness, reliability, and affordability of the cycle. In addition, the cycle's frame, wheels, and seat are designed to provide stability and comfort, and to facilitate ingress/egress.

**Propulsion:**

A wide variety of mechanisms were studied and evaluated for usability, simplicity of design, suitability for use with standard parts, and power transmission effectiveness. Ultimately, a four-bar kinematic linkage was selected because of its ability to deliver power during both the upstroke and downstroke as well as best meeting the design requirements. The physical needs of the users put severe constraints on the geometry of the cycle, leading to many iterations of the linkage's specific geometry.

As seen in Figs. 3 and 4, the four-bar kinematic linkage connects the input handlebars to a rotating crank-arm (attached to the front chain rings) through a drag link. This provides a simple, direct means of transforming the rider's reciprocating input to rotation of the front chain ring, which in turn drives the standard rear wheel. The downstroke uses the triceps and pectoralis muscles, while the upstroke uses the posterior deltoid, trapezius, latissimus dorsi, and biceps. This reduces the likelihood of incurring repetitive motion injuries by spreading the load among larger and more numerous muscle groups than the hand-crank motion, which uses the anterior deltiod trapezius, biceps, and brachioradialis (3).

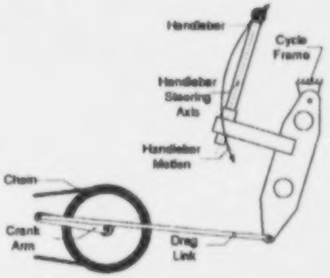

*Fig 3. Four-bar kinematic linkage*

Since the output (at the front chain rings) of the four-bar linkage is rotational motion, off-the-shelf crank arms, chain rings, chain, and derailleurs can be used in the cycle. The cycle's frame also benefits from the use of other standard components, as the rear triangle of a road bike that forms the rear portion of the cycle's frame. The result of these selections is a simple, robust, and reliable means of transforming the optimal motion for power input into propulsion of the cycle.

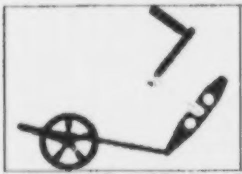
*Fig. 4a: Top of Stroke*

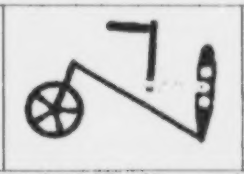
*Fig 4b: Middle of Downstroke*

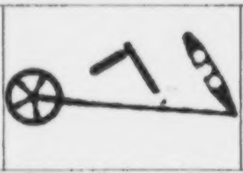
*Fig. 4c: Bottom of Stroke*

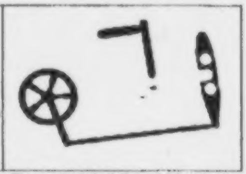
*Fig 4d: Middle of Upstroke*

**Steering:**

Steering is accomplished through the same handlebars that the rider uses to propel the cycle. The handlebars can turn about their steering axes and are coupled to each other and to the front wheels' steering arms via a cable system. By turning the handlebars, (in the same manner as with a conventional bicycle) the rider is conveniently able to steer the front wheels. Standard bicycle headsets are used to attach the handlebars to the linkage, thus allowing this requisite rotation. This reduces the cycle's complexity, and allows the rider to continue to provide propulsion power while steering. The front wheels' geometry tracks the cycle in a straight line by using positive caster and kingpin inclination, allowing the cyclist's attention to be focused on the ride itself, not constantly correcting the direction of the cycle.

**User Seating / Setup:**

In order to accommodate the specific needs of paraplegics or lower limb amputees, the seat of the cycle incorporates substantial support, comfort, and adjustability for different heights and builds of users. Angling the seat plane up from horizontal, as is done in many racing wheelchairs, creates a position that places the pelvis slightly behind the shoulders, allowing for a greater range of motion. This configuration also allows the rider's body weight to pull them down into the wedge of the seat, improving their support and stability. The design includes adjustment for inclination angle, fore and aft position, as well as the amount of 'dump' in the slung seat, to permit customization of the cycle to each rider's preferences.

**Acknowledgements:**

Dave Pringle, Curt Ramsey, Marcia Margolis, Barb Leudke, Tim Austin, Corbin Beau, Matt Flynn, Kreg Guben, and Tim Gattenby all made contributions to this project.

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# THE MULTI-PORT SIP-AND-PUFF SWITCH

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## ABSTRACT

This invention allows the control of multiple adaptive equipment via a single sip-and-puff switch. Under the control of a microprocessor the device operates in two stages. In the standby stage the user can choose specific equipment via scrolling light emitting diodes. In the activation stage the user is connected to the chosen equipment via either a relay or a pneumatic tube. A watchdog timer is used to return from activation to standby when there is a lack of activity. This device increases the independence of a person with disability by accessing multiple equipment at the ease of a single sip-and-puff switch. A US patent application for this invention is currently pending.

## BACKGROUND

Based on the latest statistics from the National Institute on Disability and Rehabilitation Research (1), one out of every 10 people in the United States has a minor disability and another out of the 10 lives with a severe disability. It is estimated that over 24 million people in the United States can be considered to have a severe disability. Many of these people use a single switch, such as the sip-and-puff switch, to drive a wheel chair, communicate, and/or control their environment. These people may have conditions including quadriplegia, cerebral palsy, head injury, spinal cord injury, severe arthritis, multiple sclerosis, muscular dystrophy, spinal muscular atrophy, Parkinson's disease, and other neuromuscular diseases.

Assistive technologies have significantly improved the independence and the quality of life for many individuals with disabilities. To use an assistive technology device, the human-machine interface is often the first problem to resolve. This invention is motivated by the problem of having multiple sip-and-puff tubes to control the various assistive technologies. For example, a quadriplegic patient may need to simultaneously control a power wheel chair, a chair inclination apparatus, an environmental control unit, and a speech communication device; each equipment has its own sip-and-puff or single switch. Access of more than one sip-and-puff switch can be problematic. Multiple sip-and-puff tubes can create congestion in front of the patient's face. They can also easily shift out of the reachable area of the patient.

## STATEMENT OF THE PROBLEM

The multi-port sip-and-puff switch (a.k.a. the EZPuff) was designed to reduce congestion of multiple switches around the mouth. Having only one input switch, the EZPuff can connect to multiple devices needing either electrical or pneumatic controls. For the present design the input is a sip-and-puff tube and the output ports are limited to four. The design can easily be extended to other types of single-switch inputs and more than 4 output ports. The pneumatic output ports are important. Some equipment such as a power wheel chair may require up to four switching actions from a sip-and-puff tube, i.e. pressure, high pressure, vacuum, and high vacuum. In such case the

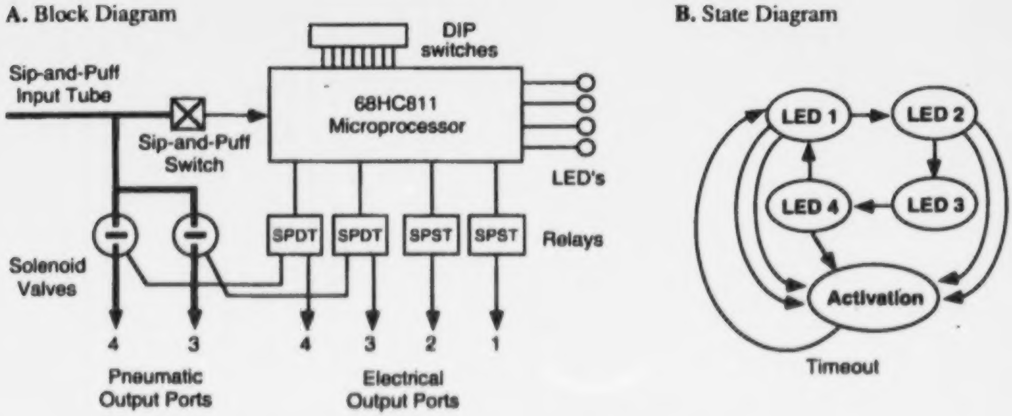
A. Block Diagram
DIP switches
Sip-and-Puff Input Tube
68HC811 Microprocessor
Sip-and-Puff Switch
LED's
SPDT
SPDT
SPST
SPST
Relays
Solenoid Valves
4
3
4
3
2
1
Pneumatic Output Ports
Electrical Output Ports
B. State Diagram
LED 1
LED 2
LED 4
LED 3
Activation
Timeout

**Figure 1.** Block diagram and state diagram for the *EZPuff* multi-port sip-and-puff system.

EZPuff establishes a pneumatic path directly to the target device without attempting to decode the different switching actions.

## DESIGN

The block diagram of the EZPuff system is shown in Fig. 1A. The core of the device is a Motorola 68HC811 microprocessor. The only input to the microprocessor is a sip-and-puff switch. The outputs include four electrical ports, each providing an on-off switch from a relay. Ports 1 and 2 are driven by single-pole-single-throw (SPST) relays. Ports 3 and 4 are driven by single-pole-double-throw (SPDT) relays, which also control two solenoid valves for the pneumatic output ports. In other words, ports 3 and 4 provide the possibility of having either a pneumatic output or an electrical output.

The state diagram in Fig. 1B shows the operation of the EZPuff. In the standby mode the four light emitting diodes (LED's) indicate the choices of the devices and scroll continuously. When a device is chosen, the operation moves from the standby stage to the activation stage. The chosen output port is activated. If the output is an electrical port, the corresponding relay is switching based on the input sip-and-puff switch. If the output port is pneumatic, the input sip-and-puff airway is directed to the designated output port by turning on the corresponding solenoid valve. During the activation stage the microprocessor implements a watchdog timer. The timer is reset by any activity on the sip-and puff switch. If the timer expires due to lack of activity, the operation returns to the standby stage.

An 8-bit dual-inline-package (DIP) Switch provides programmability for the EZPuff. They allow the user to change between electrical and pneumatic ports, the scrolling speed of the LED's, the number of devices to be controlled (between two and four), and the timeout period of the watchdog timer.

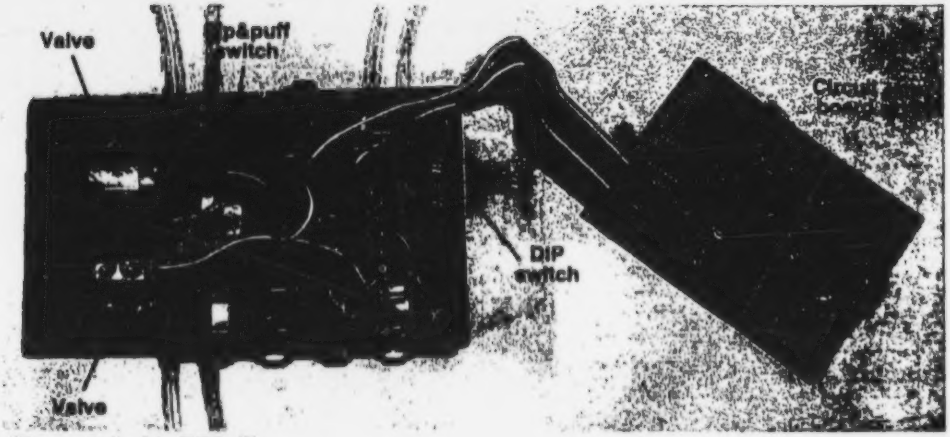

**Figure 2.** Inside EZPuff.

The circuit was designed with the help of an electronics design automation (EDA) tool, i.e. Protel. The schematic diagram of the circuit is included in the Appendix. The circuit contained 8 integrated-circuit (IC) chips. There is a total of 25 discrete components plus two connectors. As shown in Fig. 2 the circuit was built on a 3.25" x 4.5" through-hole protoboard by point-to-point soldering. The entire system fits into a plastic enclosure measured 3.5" x 6" x 2". The power supply comes from an external 6.5-volt AC-to-DC adapter. A voltage regulator on the circuit board provides regulated 5V DC supply to the system. The software for EZPuff was coded in the 6811 assembly language. The program used up about a quarter of the 2K-byte on-chip EEPROM. The software development was accomplished on a PC and a Motorola 6811 Evaluation Module. The material cost for the prototype EZPuff was about $80.

## DISCUSSION

The EZ Puff simplifies the use of multiple assistive technology devices and greatly reduces the need for assistance because there is only one switch in use. A possible weakness of this invention is the amount of time that is required to change from controlling one device to another. A minimal amount of skill will be necessary to utilize and maintain the EZPuff. This device can also be adapted to suit different switching needs of patients, thereby broadening the application area.

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**Acknowledgment** – This project was supported by the Rhode Island Department of Mental Health, Retardation and Hospitals and the URI Partnership in Physiological Measurements and Computing.

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## STUDENT MENTORING FOR THE DESIGN OF ASSISTIVE TECHNOLOGY DEVICES

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### ABSTRACT

An important factor for successful completion of design projects is mentoring the team.(1) We describe an approach to mentor pairs of students where one student is designated the senior member, and the other student is the junior member. The senior team member is selected for his/her experience in designing Assistive Technology (AT) devices, and is also responsible for mentoring the junior member. Each team member is responsible for completing an independent project. This approach led to successful project completion, encouraged independent thought, and also fostered teamwork skills. This approach minimized problems normally associated with small teams working on a short-term summer project and reduced the dependence of students on a faculty mentor.

### BACKGROUND

As part of a National Science Foundation (NSF) grant, students at Michigan Tech have been designing four AT devices per year, primarily for students in our local schools. The teams consist of 3-4 students, and spend an academic year designing and building the devices. One such device, the Thoracic Pressure Chair, has been submitted to this year's RESNA student design competition.

Based on a successful first year, funding was requested for two summer projects. Funding was obtained for two students through the NSF Research Experience for Undergraduates program. Summer projects provide unique challenges. During an academic year, four students (on average) work for 30 weeks on a project, but during a 12-week summer period, it is not possible for two students to work the same number of hours. A multi-person team can also benefit from a broader range of knowledge, which allows team members to learn from each other's unique experiences in a collaborative manner. A multi-person team is also able to break complex tasks into several pieces that one or two team members can complete. This allows for more complex devices and faster development of products once the tasks have been identified.

### OBJECTIVE

Our objective was to develop a summer design experience for two undergraduate students that would emphasize the strengths of the students and minimize the disadvantages of working in a smaller group for a shorter length of time than in the traditional academic-year experience.

### APPROACH

Each student was assigned a project that was smaller in scope than a yearlong project. Although the projects were challenging, they were judged by the faculty mentor to be appropriate for a 12-week period. An important element in teamwork is individual accountability,(2) therefore, each student was primarily responsible for his or her own project. The students were also expected and encouraged to collaborate.

Student selection is critical when forming teams.(3) Applications were reviewed from students who had already completed an AT project in the senior design sequence at Michigan Tech, but who had not yet obtained their undergraduate degree. The selected student, Jeff Klein, was designated the senior member of the team, and was given special responsibilities. In addition to his individual project, Jeff was also responsible for mentoring and assisting the junior member of the team. A second student was selected who had not yet completed the senior design course. This junior member of the team, Nicole Gabriel, had little design experience prior to this summer experience. Jeff was responsible for designing a device that would blow up a balloon by either pressing a switch or operating a hand pump. Nicole was responsible for a device that would allow for a variety of switches and sensory items (lights, tape recorders, etc.) to be placed around a child with multiple physical and mental impairments.

Although team meetings were held weekly with the faculty mentor, the students often initiated more frequent contact when problems arose. In team meetings, expectations for the week were set. Often, these expectations involved steps in the design process such as developing design criteria for the device, evaluating design options and writing reports. Jeff was experienced with this design process, and was asked to further explain these concepts to Nicole as necessary. The students were also encouraged to share their preliminary ideas with each other before meeting again with the faculty mentor. After the summer design experience, the students were asked to provide feedback to the faculty mentor so that the approach could be evaluated and improved.

## RESULTS

Both team members successfully completely their projects. Figure 1 shows Jeff demonstrating his Flying Balloons device to a child in the classroom. It is fun for the students, and emphasizes cause and effect relationships. It also encourages students to exercise using the hand pump. Figure 2 shows Nicole demonstrating her Activity Frame to the teacher, Diane Selinger, and a student. The Activity Frame incorporates switched and non-switched outlets in a single unit, which reduces the number of electrical cords and set up time for the teachers. The frame allows for easier positioning

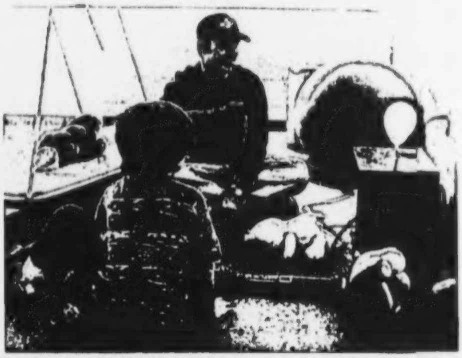

**Figure 1.** Jeff Klein demonstrates the Flying Balloons device to a student. The red box has a port on the top for the balloon. It can be blown up by a switch using a compressor, or with the hand pumps. When the balloon is inflated, it flies off of the port.

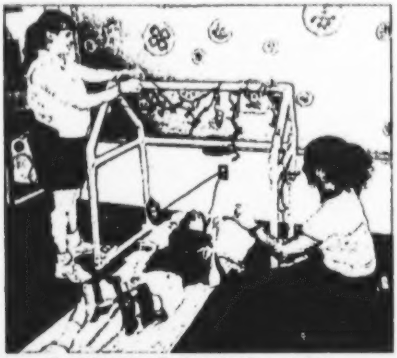

**Figure 2.** Nicole Gabriel (far right) demonstrates the Activity Frame to Diane Selinger (far left). When a student is lying under the frame, a variety of switches can be placed around him to aid his therapy and bring a sensory environment to the student.

of the various switches used in the student's therapy. Both devices received high marks from the teacher three months after delivery.

## DISCUSSION

The mentoring process for these projects worked extremely well. Jeff gained confidence in his abilities, and further reinforced the design concepts that he had learned previously. Nicole was able to ask her peer many questions and returned to the faculty mentor with questions that were more in depth and thoughtful. Nicole and Jeff felt an enormous responsibility for the completion of their individual device, but also realized the benefit of teamwork when discussing difficult concepts. Nicole was able to learn from Jeff's prior experiences, and this helped her to avoid some of common mistakes for a first time designer.

On the negative side, both students felt that their ability to help each other was limited by their lack of broad and varied experiences. Nicole said, "Because we were both young adults and students of engineering, we tended to look at the projects with the same concerns or ideas." This limitation is difficult to address when only two students are available for the team. One approach is to ensure that the students have adequate access to other faculty and resources that could help provide them with a varied outlook on a given problem.

In summary, team mentoring with two students can be successfully achieved with a senior and junior team member. When each team member has an individual project, independent thinking and responsibility is encouraged. The senior team member can be responsible for some of the mentoring, which allows the junior member to learn from a peer, and lessens the dependence on a faculty advisor. Students then also learn the importance of teamwork and how to rely on each other.

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# SEEING MS OFFICE IN A WHOLE NEW LIGHT:
# A CASE STUDY ON TURNING EVERYDAY FEATURES INTO LOW VISION TOOLS

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## ABSTRACT

This paper will show how standard features in MS Office enabled a NIDRR* Summer Scholar to derive great benefit from visual screen access. Unaware that computer images could be enhanced so he could see them, he accessed computer text via a screen reader with synthetic speech, and had no access to computer graphics. By using applications features not considered accessibility tools, he was finally able to see graphs he generated with mathematical formulas, symbol shapes he used in these formulas, and graphics in general. He eventually used a mouse to create his own graphics.

## BACKGROUND

Between the black and white of blind and sighted lies the fuzzy world of low vision. It is often difficult to get a handle on what an individual with limited vision really sees. Even individuals with low vision may be unclear about the nature of their vision loss, and about what strategies they might use to maximize the effectiveness of their remaining vision. This is especially true for people with scotomas -- islands of loss scattered throughout the visual field. The effects of scotomas on vision depend on their location in the visual field, and their size, shape, and severity. The picture is further complicated by the fact that vision loss can vary with environmental factors such as lighting, contrast, and glare, and thus change with the time of day, the weather, etc.

Our 21 year-old mechanical engineering summer student ("J") had normal vision until age 10. He then became completely blind for a short time. Small islands of low vision started to return little by little in one eye; the other eye only regained light perception. While these islands of low vision (supplemented by hearing) are adequate to allow J to navigate indoors, they only afford him a visual acuity of 20/5000. Because he has no foveal vision, letters need to be large enough to span at least two peripheral low vision islands if he is to identify them, and nothing he sees is very clear.

J believed that Windows images could not be made large enough for him to see, and therefore accessed his computer with a "talking" screen reader. He mentioned, however, that he could see a dialog box on a computer screen, but could not read its contents. This prompted me to investigate the possibility that he might be able to see other useful information on the screen.

Both hardware and software that enhance screen viewing for low vision computer users are commercially available, but given that J would be with us just a few months, I sought an instant, no-cost solution that would give us independent control of all image parameters without the need for bulky hardware or special software installation. MS Windows comes with accessibility tools, but other than changing the cursor's appearance, these do not offer the flexibility needed by someone with such limited vision.

## OBJECTIVE

We wanted to learn if standard features of Microsoft Office and other applications, although not intended as low vision tools, could provide us with simple, no-cost ways of enhancing screen images to make them visually useful to someone with extremely low acuity.

## APPROACH

The "approach" described below was not laid out in advance. Each new step was determined by J's ability to handle the previous step, his interests, and his needs.

To prepare for J's first step toward using the screen, I modified parameters to optimize what he could see based on some initial informal experimenting. In Microsoft Word this led to making the document background black, the text yellow, and the font 1000 point Arial. To maximize screen contrast, we worked in a fairly dark room.

We started by having J look at single letters of the Greek alphabet (he was curious to see the shapes of the symbols he used in his mathematical formulas). These were so large that they filled the screen. We then added individual English letters. We soon switched to looking at the letters in PowerPoint where such large fonts are more easily handled as you can: (1.) treat text as an object and easily place it anywhere on the screen, (2.) change font color with 2 strokes, and (3.) have better control of content display thanks to the discrete nature of slides.

PowerPoint also encouraged us to learn if J could benefit from visual access to *graphics*. I made a new default template based on J's visual preferences: black background, large yellow Arial font, and an AutoShape default with bright blue fill and thick pink lines.

Because his vision was so limited, it is more accurate to say that he examined images rather than saw them. That is, he visually traced them, and then cognitively assembled them. We spent a lot of time discussing what was on the screen. Sometimes I asked him to touch a specific feature of an image, or to trace its outline with his finger as he traced it with his eyes.

We soon added another eye-hand coordination task: using the arrow keys to move one graphic across another while visually tracking its movement. To facilitate his selecting graphics, I used a Windows feature to make his cursor extra large and "inverted," i.e. it becomes a contrasting color(s) to whatever lies under it. J then progressed to using the mouse to move objects, and finally to "draw" on the screen. He used the pen feature available in Slide Show View to scribble in red all over a yellow image on a black background, all the while visually tracking his work on the screen. His success with this eye-hand coordination skill allowed him to advance to using his mouse to generate AutoShapes. At this point our sessions combined J's learning to know what to look for on the screen with learning how to use PowerPoint as a graphics-generating tool. I showed him how to add lines, change line thickness, recolor objects, duplicate and move objects, insert clipart, and eventually use the animation tools and add sound. The most demanding visual task we worked on was using the cursor to grab an object's selection handle, and then drag it to a new size or shape.

By the end of the summer we enhanced graphs in Excel and MATLAB, altering the colors of the curves and backgrounds, thickening curves, and enlarging axis labels.

## RESULTS

The student who once accessed his computer only via a screen reader, left our summer program with many new visual skills. Not only was he was able to see modified text and graphics on a computer screen, but he was able to generate his own images using a mouse while visually monitoring these on the screen. With time and eye-hand coordination practice, he was able to locate smaller and smaller image features, and eventually could find the small selection handles around an object, contact them with the cursor, and drag them to a new size or shape. As a result of these various skills, J was able to draw schematics of the project he was working on at our RERC, and present them in PowerPoint. He said that he had been the only member of his class who hadn't given a PowerPoint presentation, and he was planning to remedy that during the new school year. His new skills will even let him see the graphs he generates in MATLAB, and incorporate these into PowerPoint presentations.

Despite his success with visually accessing graphics, it soon became apparent that J should continue to use his screen reader for accessing text, Windows menus and buttons. Reading extremely large text on the screen is much too slow and laborious for him to be practical.

## DISCUSSION

J's experience at Smith-Kettlewell demonstrates that visual acuity numbers alone may grossly underestimate one's ability to see useful information on a computer screen. Unlike the acuity chart's black letters on a white background, computer displays let you define the colors of text, graphics and background. In addition, the computer screen is generally brighter than an acuity chart. All of these factors can enhance visibility for the low vision viewer.

Another vital factor is the nature of the image. Visual acuity measures the ability to identify a letter. When J "draws" a shape by dragging an oval tool or a rectangle tool, he merely needs to see a bit of an edge to know which he is looking at. If he prefers, he can code them by color. His impressive ability to see small selection handles, a minuscule fraction of the size of the smallest letter he could read on the acuity chart, brings up another important point. Unlike reading an acuity chart where letter shapes have to be *recognized*, to find a selection handle merely requires the *detection* of an entity. Furthermore, because of the special template he used, that entity was a small, white square against a black background and close to an object.

J's experience also demonstrated that someone with extremely low vision might greatly benefit from standard features available in Microsoft Office applications. It would be interesting to compare the benefit J derived from this cost-free approach with what he might derive from the hardware and software designed for low vision users.

A final, critical point is that J is extremely motivated and patient. He spent much time and effort finding images, visually scanning them, making sense out of them, and working with them.

## ACKNOWLEDGMENTS

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Special thanks go to August Colenbrander, M.D. for testing J, and for generally contributing his extraordinary expertise to our understanding of low vision.

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# ASSISTIVE TECHNOLOGY OUTCOMES AND STUDENTS WITH MILD DISABILITES: POLICY INITIATIVES

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## ABSTRACT

While current federal law requires consideration of assistive technology when planning the educational programs for all students with a disability, students with mild disabilities apparently are under-served in this regard. This session will describe policy initiatives that have emerged from an innovative personnel preparation grant focusing on assistive technology for students with mild disabilities.

## BACKGROUND

The use of technology in special education technology has evolved considerably in the 1990s. Therefore, it is somewhat surprising that literature searches using the descriptors "assistive technology" and "mild disabilities" yield very few articles (Behrmann, 1994; Bryant, Bryant, & Raskind, 1998, Raskind, Higgins, Slaff, & Shaw, 1998), book chapters (Okolo, 2000), or conference papers (Edyburn, 1996) given the prevalance of assistive technology and the fact that mild disabilities are high incidence.

## STATEMENT OF THE PROBLEM

One explanation for the limited attention to assistive technology and mild disabilities suggests that the area is still in its infancy. Indeed, this perspective can be supported from a historical viewpoint as well as from a policy perspective. Historically, assistive technology devices and services have been associated with individuals with physical and sensory impairments and whose needs were moderate or severe. As special educators were introduced to assistive technology in the forms of alternative keyboards, switches, and Braille printers, it is certainly understandable that the application of these tools for students with mild disabilities were not readily apparent. However, new language in the Individuals with Disabilities Education Act (I.D.E.A.) Amendments of 1997 (Public Law 105-17) now requires that assistive technology be considered when planning the individualized educational program (I.E.P.) of all students with disabilities. Thus, the 1997 reauthorization of I.D.E.A. serves as a marker event defining a new era relative to mild disabilities and assistive technology.

## POLICY INITIATIVES

The purpose of this paper is to advance four new directions (Edyburn, 2000) that offer promise for capturing the potential of assistive technology for students with mild disabilities. Each topic will be briefly examined as it relates to understanding assistive technology outcomes for high incidence disabilities along with new policy initiatives for addressing this underserved population.

### Recognizing the Contributions and Limitations of Technology for Enhancing Performance

When attempting to design interventions that enhance human performance, conceptual models can inform our understanding of the contributions and limitations of assistive technology for individuals with disabilities. Wile (1996) studied five common models of human performance technology and sought to reconcile the differences through a normalization process to produce a synthesis of the many dimensions that have been identified as contributing to performance. Wile's analysis suggests that performance can be affected by seven variables: (1) organizational systems, (2) incentives, (3) cognitive support, (4) tools, (5) physical environment, (6) skills/knowledge, and (7) inherent ability. The variables can be viewed as part of two classes: those that are internal to the performer (#6 & #7) and those that are external (#1, #2, #3, #4, #5). Further, the external variables can be understood as part of environmental factors, or intangibles, (#1 & #2) and resources, or tangibles (#3, #4, & #5). Performance problems may be traced to a single variable or a combination

Models of human performance can contribute to the development of performance support strategies that utilize technology. Specifically in Wile's model, variables #3 (cognitive support) and #4 (tools), suggest the value of identifying devices and tools that augment and extend cognitive functioning as a strategy for enhancing performance. One powerful example of a cognitive support stategy has been described by Edmunds (1999) in the form of "cognitive credit cards." Students are encouraged to create their own performance support card, the size of a credit card, and utilize this information whenever they bring it to class

Reconceptualize the Forms of Assistive Technology

When human performance is the primary focus, the definition of assistive technology is necessarily broad as we seek to use any and all conceivable resources to enhance a person's performance. Whereas the application of assistive technology is obviously apparent in situations involving impairments that limit mobility, sensory perception, and communication, what does it mean to enhance the performance of a learner?

In considering the needs of students with mild disabilities for assistive technology, it seems apparent that additional research and development is needed to identify devices and tools that augment and extend cognitive functioning as a strategy for enhancing performance. Such applications have been previously referred to as "cognitive technologies," intelligence extenders," "cognitive workbenches," or "mental prostheses," (Office of Technology Assessment, 1988).

Redesign Assistive Technology Service Delivery Systems

Current service delivery systems for providing assistive technology services in schools do not appear capable of being scaled-up to meet the needs of students with high incidence disabilities. Therefore, a new system needs to be developed where the first step in accessing assistive technology devices and services is not a referral for an in-depth evaluation using a process that mirrors the traditional model of special education referral and placement.

An historical parallel is the development of pre-referral interventions. In the context of assistive technology, this could be accomplished by creating and disseminating various types of toolkits that have been designed to enhance performance in teaching and learning. Edyburn (2000) has described the development of three specific kinds of toolkits that could proactively meet the high incidence disability students' need for performance supports: learner productivity toolkits, assitive technology core toolkits, and toolkits for teachers.

Document the Impact, Effectiveness and Outcome of Assistive Technology

In recent years, schools have demonstrated a willingness to devote an increasing percentage of their budets to the purchase of assistive and instructional technology, there is little evidence documenting the impact of these expenditures. Because of the scale and scope of the issues involved in acquiring and implementing assistive technology for high incidence mild disabilities, accountability considerations must be addressed.

Zabala & Korsten (1999) have suggested that a series of changes can be expected when assistive technology is used effectively: quality, quantity, accuracy, rate, frequency, spontaneity, independence, and other. These indicators provide a useful framework for developing a measurement and decision-making system concerning the effective use of assistive technology.

## DISCUSSION

Given current estimates of school-aged students with disabilities at 3.2 million, it is clear that existing assistive technology service delivery models will not meet the needs of students with high incidence disabilities due to the significant challenge associated with "scaling up." The purpose of this paper has been to draw attention to the critical issues associated with this aspect of assistive technology that will limit the achievement of important assistive technology outcomes for persons with mild disabilities. Four initiatives have been briefly described for local, state, and federal policy makers to consider. Implementation of ideas similar to these will foster new assistive technology service delivery systems that can expressly address the huge under-served population of students with mild disabilities.

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# DESIGN OF ASSISTIVE ART DEVICES FOR HIGH SCHOOL STUDENTS WITH DISABILITIES

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## ABSTRACT

The Adaptive Art Department of Milwaukee Public Schools (MPS) and the Industrial Design Program of the Milwaukee Institute Art & Design (MIAD) have collaborated over the last six years to create assistive devices to aid students with disabilities perform various type of activities in their art classes.

## BACKGROUND

Most drawing or painting related accessories such as paint brushes, paint tubes, crayons, markers, easels, scissors, etc, are not designed to be easily held or used by individuals with disabilities and especially those with hand function limitations.

## RESEARCH QUESTION

The purpose of this collaboration is to design assistive art devices, such as marker holders, adapters for crayons and color pencils, wheelchair based easels, etc., to increase the student's ability to complete art assignments as independently as possible.

## METHOD

An iterative process of design, prototype fabrication and hands-on evaluation in the participating schools with teachers, art therapists and students is used to develop the new assistive art devices.

Students from the high schools are paired with the industrial design (ID) students. Then teachers and therapists provide information to the ID students about the needs of the high school students they are paired with. The information provided is related to the student's functional capabilities resulting from their disabilities and their ability to perform art related tasks.

From this interaction, the ID students select assistive art devices to be redesigned, establish design criteria and begin the design process in collaboration with the Adaptive art therapists, the high school teachers and their MIAD professor.

This design process involves first an ideation phase consisting of two-dimensional (2D) sketches and three-dimensional (3D) foam or wood scale mock-ups to conceptualize the new designs.

## DESIGN OF ASSISTIVE ART DEVICES

The drawings and mock-ups resulting from ideation are then presented to the teachers, art therapists and each student for input on their purpose and usability.

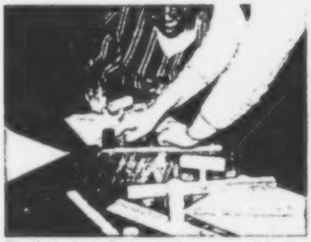
From the evaluation results, the ID students refine their designs to a new level of functionality. The refined or final designs are then made into final or functional prototypes that are presented to the teachers adaptive art therapist and the students for actual use in the classroom.

Since the beginning of this collaborative project, numerous new assistive art devices were developed including, new paper cutting devices, pencil and marker holders, easy to use rulers, and easels accessible from wheelchairs.

Paper cutter

Paper cutter in use

Pencil holder

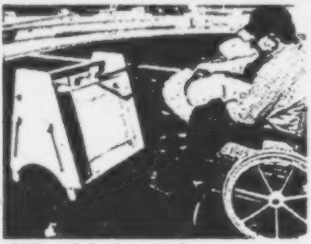

Ruler mockups

Ruler mockups

Assisted use scissors

Marker holder

Wheelchair easel


Wheelchair easel

## RESULTS

This ongoing collaboration has consistently received local media attention. The final presentation of new assistive art devices appears every year in newspapers and local television news.

This collaboration highlights the value of such endeavors for both institutions and the public at large. Furthermore, this successful collaboration is invaluable for ID students to become aware that their future clients will include the entire population, young and old, able bodied and disabled.

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# A FEEDBACK ENHANCED ASSISTIVE BOWLING DEVICE

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## ABSTRACT

Recreational activities form an integral part of students' successful development. Opportunities for participation in physical education are often limited for people with physical disabilities. This paper describes the design and prototyping of an exciting new feedback enhanced assistive bowling device for students with cerebral palsy. This unique assistive bowling device facilitates participation, inclusion and independence for students via an elaborate, exciting and unconventional selection of feedback options.

## BACKGROUND AND PROBLEM STATEMENT

Westlake High School in Austin, Texas is renowned for its competitive athletic teams. Unfortunately, some students are not able to be included in aspects of physical education class let alone participate in competitive sports. The Feedback Enhanced Assistive Bowling Device presented in this paper was designed for four West Lake students. The students have cerebral palsy[1] that manifests itself as limited vision for one user, spastic movement for another and reduced mental and physiological capacity for all four.

The Feedback Enhanced Assistive Bowling Device designed for these students replaces a metal ramp that was unsuitable for their specific needs and requirements. This ramp did not accommodate wheelchairs of varying heights, or allow the wheelchair user to fit beneath the ramp and view the ball at close range. Finally, it was unstable and activation of the device was confined to hand-over-hand assistance, not the preferred choice of independence for the user.

## ANALYSIS AND CONCEPT GENERATION

*Gathering Customer Needs:* The design problem mandated the use of design methodologies to satisfy customer requirements. These customer needs included: customizable sensory feedback, independence and inclusion for user, social participation, portability, stability, height adjustment and safety. The customer needs were prioritized and transformed into engineering metrics, measured using the House of Quality, a Quality Function Deployment (QFD) technique that resulted in the generation of the target specifications for the intended design.

*Concept Generation:* The problem statement was divided into individual functional modules. Solutions were devised for each function using the traditional techniques of brainstorming augmented with the more novel ideas of brain writing and Pugh Charts [2]. The team then generated multiple concepts variants for a Feedback Enhanced Assistive Bowling Device and synthesized them into complete design ideas.

*Concept Selection:* The process of concept generation integrated customer needs with design concepts. Functional modeling [2] was used to divide the device into the following modules: height adjustment, holding and locking the ball, activation, customizable sensory feedback, and stability. The design team surveyed the students, their families and teachers for the student's preferences.

Next, we selected the specific types of stimulating and positive reaction generating feedback to be incorporated into the device. One student's parent told us that her daughter was particularly enamored with the sound of bodily functions like hick-ups, burps or farts. Therefore, the team used an off-the-shelf product called the "Fart Machine" from Spencer Gifts [3] to see empirically that this particular sound was indeed enjoyed by the students. This device was later used to record one of the audio feedback choices for the bowling device.

Customer requirements of stability and feedback governed material selection for the project. After thorough discussion, proof of concept prototypes, and synthesis, the resulting concept variants combined the ideas of using a frame and ramp made of clear PVC pipe [3] with a clear electronics box and plate-dome assembly. The former housed the lights for visual feedback and the latter the electronics needed for ball activation and audio feedback as well as the functions of holding and locking the ball. The materials selected were Lexan for the electronics box and dome and Acrylic for the plate assembly. This ensured the necessary strength, coupled with a modern and aesthetic appearance that the customer desired.

## DESIGN AND DEVELOPMENT

Ball activation was achieved through the action of a pull solenoid affixed to a flap on the plate that held the ball in place. The plate incorporated a set of rails that guide the ball directly toward the flap. The flap linked to the solenoid via two rods that extend into the control box. In addition, the solenoid was also attached to a spring giving it the restoring force required for getting the flap back in place after activation. The appropriate ball acceleration was achieved via the potential energy from the ball's height. This translated to a velocity that was comparable to high school student bowlers without cerebral palsy. The device is disassemblable and suitable for use in a classroom or bowling alley.

The extensive feedback system includes standard, off the shelf, holiday lights, and the noises of a pig, horse, fart and harmonica. The clear ramp and frame enclose the holiday lights. The control box, which plugs into a standard AC wall outlet, provides power to illuminate these lights. Four different sound patterns, pre-recorded by the design team during the development process, provide the audio feedback.

After much debate, the design team adopted an ingenuous yet simple concept for height adjustment. T-joints bored to different levels of collar depth attached to the ends of two white PVC bars. These supports for the legs of the frame can be easily rotated 180° to yield different heights. Two cross bars made of clear PVC coupled to snap fitting standard PVC T-joints further enhance stability.

The structure of the frame used clear PVC for straight portions along with L and T-joints made of conventional white PVC. Opaque joints were chosen because they were significantly less expensive than clear joints. The use of a heat blanket and an appropriately, previously bent, white PVC pipe mold ensured uniformity of bending and repeatability respectively for the two ramp rails.

## DESIGN EVALUATION AND CONCLUSIONS

This challenging and meaningful project culminated in a beta prototype that is exciting and stimulating for the student users. It embodies all of the customer needs, enabling the four student customers to participate in physical education and be included with other students in their class.

The device provides them with unique, immediate, and customizable feedback that they have activated the device and bowled the ball even if they are cannot see far enough to view the pins going down. The students can see through the stand, ramp and electronics box to see what is happening and view the feedback while hearing their choice of audio feedback.

*Figure 1. Photo of Kelly enjoying the feedback enhanced bowling device*

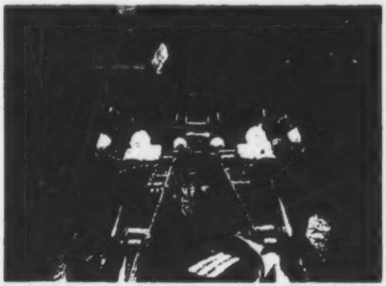

*Figure 2. Photo of user's view of bowling device*

*Figure 3. Isometric view of CAD drawing*

## ACKNOWLEDGEMENTS

We would like to convey our deep gratitude to Ms. Pegi Pickett, and Ms. Elizabeth Danner, the home and community teachers at Westlake High School, and Ms. Kathleen King, the assistive technology coordinator for Eanes ISD. We are indebted to our professors Dr. Kristin L. Wood and Dr. Richard H. Crawford for providing design methodology, inspiration and encouragement. Our thanks are not complete without acknowledging the importance of our student customers, Aisha, Sally-Ann, Kelly and Courtney.

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# DESIGN OF A SWITCH ACTIVATED BALL TOSSER

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## ABSTRACT

This paper presents the development and design of a switch activated ball tosser to integrate children with disabilities into normal recreational activities. Ball tossing games such as basketball pose a great challenge to people with mobility impairments, as they require motor and cognitive skills. The goal of this project is to facilitate the inclusion of children with physical and mental disabilities in the game of basketball.

## BACKGROUND AND PROBLEM STATEMENT

The device presented in this paper was originally designed for the students of the Rosedale School, Austin who have motor disabilities. One of the teachers at the school wanted to facilitate her students taking part in a basketball game. Her needs were for a device that would toss the ball with different ranges, be portable and durable. She wanted the device to be activated by "Big Mac" switches which they were using and which the students were familiar with. The device was also expected to be capable of adapting to the skill level of the student.

The products that were available on the market were not able to satisfy all these needs of the school and were also too expensive. Thus we started off designing this Basketball tosser for the students of the Rosedale School.

## DESIGN METHODOLOGY

### Gathering Customer Needs:

The first phase of our project was focused on understanding the needs of the customer. Meetings with the teachers gave an insight into what the teachers wanted from our device and also what they disliked in the products available in the market. The experience with the children increased our involvement in the project. It also helped us get a clear view of what motor disabilities they were suffering from which was a main input for designing the machine. The facial expressions of the children made us realize what sounds and effects they liked and what they disliked. The customer needs were listed and prioritized. The House of Quality was created to know the interdependencies between the various customer needs and where compromises have to be made. This led to the concept generation phase.

### Concept Generation:

The next phase of our projects involved generating concepts to meet the customer needs. The given problem was decomposed into functional modules using functional decomposition and analyzed individually. Various design concepts were evolved for each of the sub-modules by brain mapping, using the 6-3-5 technique and with the help of morph matrices. Approximately 50 concept variants were evolved. One of them is shown in Figure (1). There were three main groups of concepts: catapult mechanism, rotating wheels and compression spring concepts. The next stage was to narrow down to the concepts which may be feasible and which satisfied the customer needs. This was done in the concept selection phase.

### Concept Selection:

The concepts that were generated were analyzed for feasibility, and based on how well they satisfied the customer needs taking into account the weights attached to the individual needs.

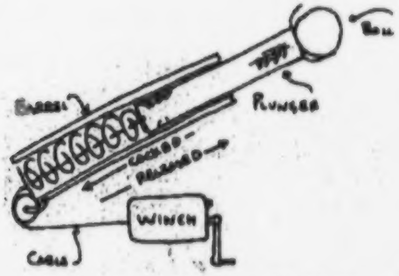

**Figure 1 – Concept Variant**

Pro/Con Chart and Pugh chart were formed to help in selecting the most promising concepts. Special consideration was also given to the simplicity of the device and to reduce the maintenance required. The catapult mechanism failed to satisfy the customer needs of varying the range easily and was also less durable. The compression spring concept and the rotating wheels concept seemed to satisfy the customer needs equally well.

So, a proof of concept for each of these concepts were made and from that we realized that the spring concept was very difficult to control, while on the other hand the rotating wheels concept proved to be simple and easy to maintain. Thus we decided to develop further on this concept.

## DESIGN AND DEVELOPMENT:

The next phase involved developing the product keeping in mind the customer needs. The decisions made were driven by how well they satisfied the customer needs and also by economic considerations. We were able to obtain valuable inputs from softball pitching devices that existed in the market. Detailed calculations were performed to determine the velocities to be achieved in order to reach the basket from a distance of 20 feet utmost and the power of the motors required to achieve them.

In order to provide for varying ranges it was decided to change the power delivered by the motor and also the angle at which the ball would be shot. A motor with 3 variable speeds was chosen for the purpose. The use of gears and transmission mechanisms were avoided to keep the machine simple and economical. Caster wheels were chosen as they withstood the high rotation speeds. The wheels were directly coupled to the motors. The motors run continuously and are operated by a rotary switch.

For the input mechanism, the concepts that were thought of were a chute and a ramp. The chute concept was eliminated because it would increase the size of the device and the ramp mechanism was chosen. The ball was held in position by means of a plate attached to a pull type solenoid. When the student presses the switch, the solenoid moves down and the ball rolls along the ramp and gets fed into the wheels.

For changing the angle of firing, holes with a pin or plunger, wedge mechanism and a screwjack were thought of. It was decided to use the screwjack, as it was very convenient to the teachers who were going to use the machine and it was very durable. The screwjack can be moved up and down by turning the lever arm, to change the angle. The angle of firing was confined to a range from 35 degrees to 60 degrees, although the device is capable of producing greater angles.

The main part of the entire device was the feedback module that would enthuse the children and get them more involved. The students were more attracted to bright and to moving objects. So a decision was made to have two fans and a light bulb that would drive colored balls spiraling up. The bulb would illuminate the balls.

In order to make the ball tosser mobile, wheels with brakes were attached to the base of the feedback module on which the tossing module would stand. The brakes, on being set, would help make the device stable during the ball tossing. A photo of the final product is given in Figure (2).

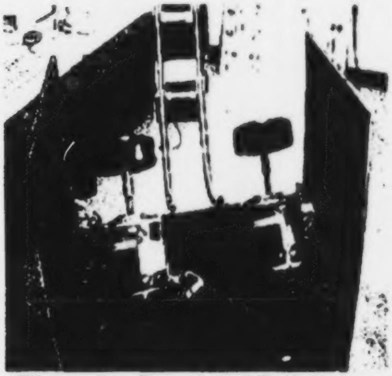

**Figure 2 – Completed Ball Tosser**

## EVALUATION AND DISCUSSION

The children at the Rosedale School and the teachers enthusiastically received the ball thrower. It succeeded in meeting their expectations, as it was economical and allowed for varying ranges. The device was able to shoot baskets from near the basket and also from a distance of 35 feet at maximum speed of the rollers.

The ball tosser is portable and allows the teacher to place it wherever she wants. The teacher needs to only feed the balls into the device and it is very easy to use. The child can use any remote switch with a standard 1/8" plug to fire the basketball. The device can be plugged into the wall socket to power the motors and hence it needs no batteries to power it up. Thus it has very low operational costs as well. Care was taken to make the device safe and durable.

It was ensured that the device was simple and could be remanufactured easily to meet the needs of other customers. A detailed bill of materials was compiled along with exploded views to help in the remanufacturing of the device. We are confident that this device would help children in many other schools, in playing basketball and bring happiness to them.

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## ACKNOWLEDGEMENTS

We express our gratitude to students, staff and teachers of Rosedale School for providing an opportunity to work for them and providing valuable assistance during the course of the project. We would also like to thank Dr. Kristin L. Wood and Dr. Richard H. Crawford for guiding us throughout the design process.

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# THE AUDIBLE COUNTER

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**ABSTRACT:** The goal of the audible counter was to design a device that could easily adapt to the individual abilities of workers at Orange Enterprises. To acquire this type of adaptability a base unit was designed with multiple input ports to which either a commercial switch or two custom-designed motion-sensing switches could be connected. In addition, both audio and visual outputs of the count are available. The final design has successfully integrated the audio and visual components and allowed for easy expandability through standardized input ports. The audible counter will be a useful tool for Orange Enterprises, adapting to the needs of current employees while having the potential to change with the changing needs of new employees.

**BACKGROUND:** Orange Enterprises (OE, Hillsborough, NC) is a company that provides employment to people with a variety of disabilities, including cerebral palsy, mental retardation, and those with visual and/or mobility impairments. The employees are paid to complete basic tasks that often involve counting an assigned number of objects for placement in supply kits or papers for work-packets. The counters used currently at OE are tiny, and difficult to increment and reset; therefore, they are not suitable for use by many employees. Designing for a range of workers poses the unique challenge of accounting for multiple types of disabilities, especially problems with vision and mobility, in the design of the counter.

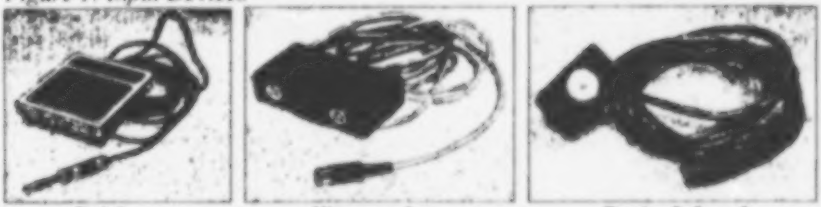
**PROBLEM STATEMENT:** The main goal of this project was to design a counter that could accurately take inputs using a variety of external switching devices and output the count with both a large visual display and clear sound. With this goal driving the project, the objectives were that it be usable by employees with a variety of disabilities, adaptable to needs of new employees, easy to use, portable, unobtrusive, rechargeable, and accept a wide range of input devices.

**RATIONALE:** Collectively, the employees at OE have a variety of disabilities that affect, in most cases, mobility, visual acuity, or both. This makes the use of most commercially available counters an ineffective solution. Workers are paid by the amount of work they get accomplished, rather than the amount of time they are on the job. Employees often say that they do not earn as much money as they would like. Providing OE with a counter that easily adapts to the needs of most employees will therefore assist them in working more efficiently and earning more money as a result.

**DESIGN AND DEVELOPMENT:** The first major step of the design process was visiting OE to observe how most employees worked, noting which limitations seemed most prevalent, and also speaking with the supervisors to derive a list of desirable features for the final product. These visits led us to develop three interchangeable input options: a foot pedal, an ultrasonic motion sensor, and a passive infrared sensor (See Figure 1).

The project was then divided into two parts that were independently developed and then integrated into a final product. The first and most challenging part was to develop a feasible audio solution. For the sake of reproducibility, it was decided that a standard set of sound files would be digitally encoded, stored on a memory chip and reproduced using a separate speech synthesizer chip. This approach would allow for easy integration with a microcontroller, which was determined to be the best way to coordinate the audio and visual outputs with the user interface. Unfortunately, after

*Figure 1: Input Devices*

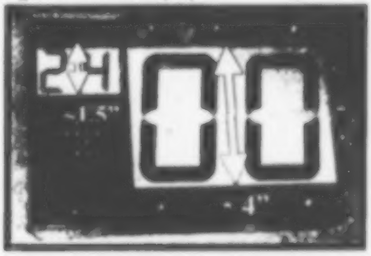


**Pedal** **Ultrasound** **Passive Infrared**

many weeks of developing this solution, it was learned that the company producing the synthesizer chips had sold off its rights to the speech hardware, which will not be supported or produced by anyone in the immediate future. With no industry support available, the speech synthesizer was no longer a feasible solution, and was replaced by an all-in-one voice record/playback chip with on-board memory. Fortunately, this new solution effectively met the objective of providing a clear audio output to the user. A differential mode audio amplifier, chosen due to its efficiency and high output power for low supply voltages, was used to drive an internal speaker. The Audible Counter additionally has a volume control and an automatically switching headphone output.

The second part of development was to design a working prototype that encompassed everything found in the final product with the exception of the audio components. It was decided through discussion with OE supervisors that although some users would be completely blind, many others would benefit from the presence of a large, easy to read visual display. Tests showed that a large LCD display met our goals for readability, power, and cost better than an LED display. Another visual feature derived from meetings with OE supervisors was the goal display on the upper left-hand corner of the device. This display allows those OE employees who do not understand the concept of numbers to detect their completion of a task by matching the incremented counter display to the static goal display.

*Figure 2: Front Display*

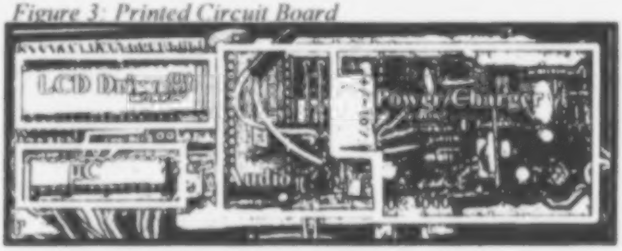


**The count is displayed on the right and the goal in the upper left.**

Another major development task was the design of a power system for the Audible Counter. The device is powered by six internal AA NiMH batteries, which require a specialized charging circuit that monitors both the voltage and temperature of the batteries during each charge cycle. These batteries will power the device for approximately one work week under moderate use, and can be recharged in 2-3 hours. A high-efficiency switching regulator was used to provide power to the sensitive microcontroller while efficiently delivering the large amounts of current required by the audio amplifier. Using this type of regulator additionally allows the device to be used while the batteries are being charged.

A double-sided printed circuit board was designed and fabricated. This was done to minimize total size, to allow for increased durability of the final product, and to accommodate the two surface mount IC's used in the device (See Figure 3). The hardware associated with parts one and two of our development phase was soldered onto the board, and then functionally integrated using software written in assembly language for a PIC microcontroller.

*Figure 3: Printed Circuit Board*



**The four major components of the PCB are boxed above**

Since its functional completion, many additional features have been added to the Audible Counter, allowing it to be further customized to the needs of individual employees. These features include an adjustable debouncing delay, an automatic power off, and input device detection.

**EVALUATION:** The Audible Counter was delivered to Orange Enterprises on schedule. However, due to the unanticipated delays caused by the failure of our first audio solution, we were not able to execute the on-site prototype testing that we had planned. Nevertheless, tests at final delivery proved to be a huge success. Those who tested it enthusiastically received the Audible Counter. Of note was one employee, afflicted with cerebral palsy and total blindness, who showed remarkable promise for completing tasks that had previous been impossible for him. Our supervisors were quite pleased with the device, which they have put into continuous use at OE.

**DISCUSSION AND CONCLUSIONS:** The advantages of the audible counter are its flexibility and adaptability, however this flexibility is not without its drawbacks. Adapting the audible counter to the specific needs of each employee requires individual testing of the different inputs, increment delays, and headphone vs. speaker preference by the supervisor. Fortunately, these test need to be done only once and to help organize and preserve this information, a chart has been included at the back of the user's manual. By using multiple modes of input and output, many employees at OE will find themselves able to work more efficiently than they ever have before, and the standardized input jacks will allow the audible counter to adapt to the changing needs of the workforce.

**ACKNOWLEDGEMENTS:** We would like to thank Dr. Larry Bohs for his guidance and support, Ms. Antonia Pedroza and Ms. Judy Stroupe at OE for their cooperation and ideas during development, Mr. Joe Owen for his help machining the enclosure and desk stand, and finally the students in BME 260 for their support and advice.

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# DreSS: THE DRESSING SUPPORT SYSTEM

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## ABSTRACT

Our client has spastic diplegic cerebral palsy, a condition where the legs are more severely affected than the arms. As a result, she has difficulty putting on pants, shoes, and socks without outside help. To increase her independence while dressing, we designed DreSS, a dressing support system, consisting of a chair, two parallel bars, a shoe/clothes rack, and a platform. Based on initial tests with our client, we expect DreSS to provide the support our client needs to dress independently.

## BACKGROUND

CP results from an injury or defect between early pregnancy and the age of three in a developing brain. Any damage to the brain is a single event; hence, it is not a progressive disorder. Damages to the brain interfere with the transmission and reception of signals between the brain and body, which causes an awkwardness of movement and control of limbs. A patient may experience any combination of muscle tightness and spasms, involuntary movement, and lack of gross and fine motor skills [1]. Children will have additional problems, such as weakness, lack of speed, and shakiness [2]. The limbs affected by CP, however, are not paralyzed, and can sense pain, temperature, and pressure [1].

Our client is a 9-year old girl diagnosed with spastic diplegic cerebral palsy. In this form, the legs are more severely affected than the arms, which is usually a result of damages to the cerebral cortex. Specifically, our client's leg muscles are resistant to stretching because the hamstrings are tight and stiff [1].

Assistive devices for dressing do exist. Sock-aids help patients wear socks without bending their legs. Shoehorns with various handle lengths are available and allow for an extended reach. Another device, the dressing stick (Sammons Preston, Inc), allows people with quadriplegia to pull up their trousers while lying down [3]. Our client's needs could not be met using the above devices. Currently, there is no commercial dressing "system" that provides upright and sitting dressing support with special features for convenience; thus, it was necessary to develop and build the customized DreSS.

## PROBLEM STATEMENT & RATIONALE

Our client finds dressing difficult for several reasons. She can only remain standing by supporting herself on a sturdy structure, and she easily loses her balance while sitting to reach her feet. Our goal with DreSS was to help our client dress by providing an upright support and a mechanism for maintaining her balance. By doing so, her sense of independence and self-esteem would improve.

After numerous tests and detailed brainstorming with our client's parents and therapists, a device was designed to include a chair, parallel bars, a shoe/clothes rack, and a platform. Special features that were included are a shoehorn, no-slip foam covers on the bars, a cushioned backrest, and height-adjustability for both the chair and parallel bars.

## DESIGN & DEVELOPMENT

Several tests with prototypes narrowed down our feasible solutions. Our client's parents and therapists suggested that a chair would most benefit our client, and her physical therapist

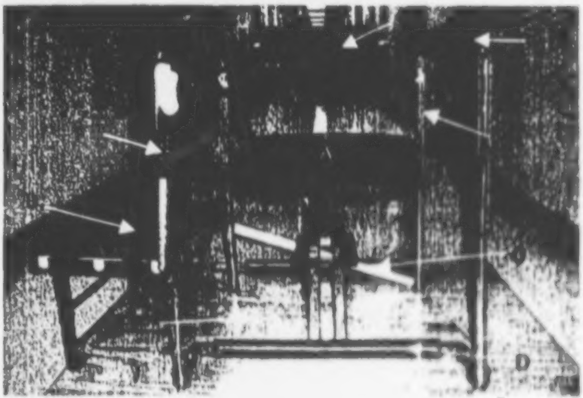

Figure 1. Parts of DreSS

recommended that a "bar structure" could provide the upright support. Another possible solution was a wedge that she would lay on while putting on her pants. The wedge, however, was unsuccessful when tested. Then a chair and parallel bars were tested with our client, who easily adapted to the bars and chair and used them to her advantage to pull up her pants and put on her shoes and socks.

A kneeling chair (Fig 1A) was chosen for its height-adjustable feature, its natural forward downward incline of the seat, and the possibility of transforming the knee rests into footrests. Initially, a footrest was a suggested part of the design, but after testing the chair, we observed that the seat's incline helped maintain our client's balance by shifting her center of gravity forward. She evidently did not need a footrest, so it was removed from the design.

The bar structure was designed for simplicity, safety, and height adjustability. The structure will minimize tripping; it will not restrain our client to the device, and its height-adjustable feature will extend the period of DreSS' use. The structure integrates side (Fig 1E) and back supports (Fig 1H), which were important safety features discussed with the therapists. The bar design was constrained by space limitations and the parents' desire for a simple yet durable structure. The steel pipes provided durability and the connectors greatly simplified the structure with small radial 60 and 90 degree bends. The bars were connected to the chair at its front leg, making the two components a single unit (Fig 1D). Spring-loaded buttons were built into the bars for height adjustment (Fig 1E).

Four alternative solutions were considered to prevent tipping. First, we could have filled the steel chair frame and bars with lead pellets to lower the center of gravity, but the total volume of the frame and bars were minimal compared to the necessary weight. Second, we could have angled the feet of the bars outward, but this created more tripping scenarios. Third, we could have bolted DreSS to our client's wooden floor, but we deemed this solution inconvenient for the client and her family. Our final solution was a wood platform (Fig 1J) because it was space efficient, safe, and aesthetically pleasing, and will provide the necessary stability. The bars were bolted to the platform at eight locations (Fig 2). A crossbeam was also attached to the bars (Fig 1G) to improve overall stability.

Elements of comfort, safety, and aesthetic appearance were also added. New upholstery was sewn with easy-to-clean, durable vinyl, replacing the woven fabric of the original chair. The color of the entire device was chosen and approved by our client and her parents. A shoe/clothes rack was attached to the device (Fig 1B). A wooden step was placed behind the front leg of the chair to prevent tripping

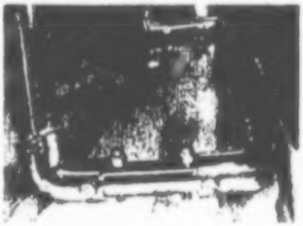

Figure 2. Bars bolted to platform

(Fig 1I). All four edges of the platform were beveled to prevent any stubbing of toes or discomfort when standing on the edge. Foam cushions on the bar served as non-slip grip handles (Fig 1C), and the backrest cushion (Fig 1H) provides comfort and safety. Finally, a shoehorn was included with a simple Velcro attachment (Fig 1F).

## EVALUATION

DreSS was tested with our client throughout the design process. The bar structure and chair visibly improved our client's ability to dress by helping her maintain her balance. Elements of support while sitting were the forward angle of the seat, side rests provided by the bars, and the backrest. The main elements of support while standing were the bars. She was also able to dress in a timelier manner.

Tipping analysis was performed quantitatively with a MATLAB program to test DreSS' stability. Results showed that DreSS is stable sideways, backwards, and forwards as long as unnatural forces are not applied and is used for its normal functions. Empirical testing confirmed the theoretical analysis.

## DISCUSSION & CONCLUSIONS

The main limitation of the device is that it is large. Size was compromised for stability and height-adjustability. To reduce space coverage, future devices of a similar nature could utilize heavier materials and have a bar design that does not rely so much on the platform weight for stability.

DreSS was built to grow with our client and is safe and aesthetically pleasing. Most importantly, we expect the device to provide the necessary dressing support without restricting our client's natural motions. In turn, this will instill a sense of independence as well as accomplishment.

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[3] The Sammons Preston Storefront. http://www.sammonspreston.com/. Accessed December 2, 2001.

## ACKNOWLEDGEMENTS

We would like to thank Dr. Laurence Bohs, our professor, for advising us through the designing and building process, Joe Owens for machining, Dr. Joseph Nadeau for helping us with the quantitative tipping analysis, and Amy Loesch and Kristi Duke for making it possible for us to test prototypes with our client at the hospital. We would especially like to thank our client's parents for their input and cooperation, and to our client herself for her patience with repeated prototype testing.

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# COUNTER FOR THE VISUALLY AND MOBILITY IMPAIRED

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## ABSTRACT

Orange Enterprises is a non-profit corporation employing adults with mental and physical disabilities to perform tasks such as the repetitive counting of objects for shipping and assembly. Most employees can perform this task with the help of a counting aid, but the current counting aid is too small to be operated easily or independently by many employees. We are providing Orange Enterprises with five digital counting aids that are easy to increment, read, and reset without the aid of a work coach. These devices will be discrete, durable, portable and powered by a rechargeable battery pack that will last an entire workweek between charges. These devices will give employees with a wider range of abilities access to an appropriate counting aid, and increase these employees' productivity, wages, and self-esteem.

## BACKGROUND

At Orange Enterprises (O.E.), employees with mental and physical disabilities are matched to tasks that best suit their individual abilities. One common task is for employees to count a prescribed number of items for shipping or assembly. Many workers need a counting aid to perform this task, and the counting aid currently in use at O.E. is a small hand-held mechanical counter that has been fixed to the work surface. The counter is incremented by actuating a small button on its top, and the current count is displayed on 1/4" high digits. Non-reading employees use this counting aid by matching the count displayed to a goal number taped to the work surface. This device does not adequately meet the needs of many of O.E.'s employees. It is too fragile and sharp-edged to be used safely by employees whose involuntary muscle spasms could cause them to strike the device forcefully. It cannot be moved from its affixed location as employees move between workstations. Its display is too small for employees with visual impairments to read, its incrementing button is too small for employees with poor manual dexterity to actuate, and the device is nearly impossible for most employees to reset without the aid of a work coach.

## PROBLEM STATEMENT

Currently, Orange Enterprises does not have a counting aid that adequately meets the needs of its employees. Many employees use the current counting aid with significant assistance from work coaches, and our supervisor has noted that O.E. could use up to 20 new counters. To help meet this need, we will provide Orange Enterprises with five digital counting devices that can be operated safely, easily, and independently by employees with a wide range of abilities. Our devices must be discrete and blend into a work environment to allow adults who feel self-consciousness about needing a counting aid to operate them comfortably. Our devices must be durable enough to withstand years of daily abuse, and must minimize the risk of worker injury.

## RATIONALE

By providing Orange Enterprises with a counting aid that is easier to increment and read, we will increase the number of employees able to perform repetitive counting tasks and increase the productivity of employees currently using the mechanical counter. Many employees at O.E. would be able to perform repetitive counting tasks if they had access to an appropriate counting aid. Employees with poor vision and limited manual strength and dexterity can use a counting aid that is easier to read and increment. Also, a device that can be reset independently will allow employees to perform more counting tasks per work day, as employees will not need to wait for a work coach to reset their counting aids before starting the next task.

## DESIGN AND DEVELOPMENT

We met with our supervisors regularly to assess and fill Orange Enterprises' needs. We found no commercially available products specifically tailored to the needs of users with physical and mental disabilities, and only a limited range of small hand-held counters like the one already in use at O.E. Therefore, we needed to design a device that met all user ease and durability objectives while being simple enough that we could assemble multiple units in a semester, and also easy enough to manufacture that future students with basic knowledge of electronics could construct additional units.

The electrical design focused on simplicity in design and minimal power consumption for greater battery life. Our device is based on a counter chip by Fairchild semiconductor (MM74C925) that receives input from the increment and reset buttons and outputs the current count by driving an LED display that is quickly lit digit-by-digit to save power consumption. To provide a large enough display while saving battery life, we found a 7-segment display with 1.5" digits that used tiny low-power LEDs to backlight each segment. Although our LED display was common anode while the counter chip was designed to drive a common cathode display, we interfaced them by inverting the driver output with NPN transistors. Also, the counter chip could only process increment signals with sharp rising edges. After debouncing the increment input signal with an RC circuit, the signal rose too slowly, but passing the signal through a CD40106BE Schmitt trigger solved this problem. An external input jack allows any commercially available switch with a 1/8" male plug to increment the device. To prevent accidental reset, we had originally planned to recess the reset buttons, but later found that a simpler reset button delayed by a RC circuit would adequately prevent accidental reset and be easier for workers to use.

We encountered difficulties in powering our device with five rechargeable NiMH batteries when a battery recharging circuit based around the Maxim Semiconductor MAX712CPE chip did not function correctly. We chose to use a high-capacity NiMH battery pack and charger set from Radio Shack instead, as this lowered unit cost and complexity.

The physical design of the counter reflected our clients' desire for the device to be discreet, easy to use, and durable. Although we had originally planned to house our devices in a custom-made 4" fiberglass pyramid-shaped enclosure with recessed reset buttons, we soon switched to commercially available enclosures to save machine and assembly time. The selected enclosure is made of aluminum with an angled display face. We had the five enclosures machined to accommodate buttons, switches, jacks and the LED display, filed off sharp edges, and coated the exteriors with protective Plasti-Dip (put manufacturer name here) and added rubber feet to increase traction and durability. Our internal construction is simple but durable. The LED display is protected from the exterior by Lucite and backed by a nylon panel. This panel is secured by bolts connecting to the enclosure on both sides of the LED display and supports the constructed circuit board via standoffs. The battery pack is also well secured, immobilized by nylon ties bolted to the enclosure's base.

Our counter uses a large, industrial strength increment button located on the top of the device (Figure 1). The increment button can be actuated with very little force applied at many angles, and has a long mechanical life (5 million cycles). The reset buttons are located on both sides of the device, and require little force to actuate (Figure 1). The back of the device (Figure 2) contains the on/off switch (left), the external input jack (right) and the battery recharger jack (far right).

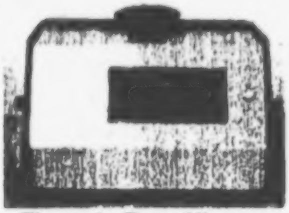

Figure 1: Front View

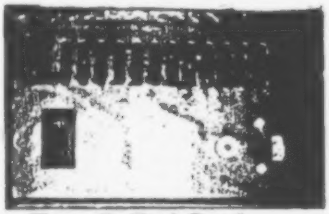

Figure 2: Back Panel

The final product is durable enough to withstand drops and even strikes with a rubber mallet. It allows for easy accessibility to all buttons and maximizes readability of the display.

## EVALUATION

To accommodate our clients' desire for batteries that would last a 40-hour workweek before recharging, power consumption was one of our main design concerns. We calculated a theoretical charge life of 40.74 hours by dividing the battery pack's 2200mAH capacity by the 54 mA current drain when the device read '000'. To verify this we ran each device at '000' until the display was too dim to read from a distance of 5 feet. Over 5 trials, the average life per charge was 54 hours, exceeding our theoretical life and client specifications.

## DISCUSSION AND CONCLUSIONS

Major advantages of our device include the large bright display, buttons that are easy to actuate, a reset delay to prevent accidental reset, a jack for additional switch input, and a long charge life. The counter is also robust, designed to withstand forcible strikes and drops from standard table height. A five to ten second warm up time is the major disadvantage of our device. After the counter is turned on, it cannot be actuated immediately. This is a function of the RC circuit that allows for the reset delay. This circuit also disables the device for a few seconds if the reset button is held down after the display resets to '000'. Future work on the device could include allowing for adjustable sensitivity to rapid actuations, to accommodate users with more spasticity of motion. Replacing the resistor in the RC delay circuit with a potentiometer would allow work coaches to change the time constant and consequently its sensitivity to match each worker. The Counter for the Visually and Mobility Impaired was a success: we designed and produced five devices for Orange Enterprises. The final products met all objectives and will provide increased independence for workers at Orange Enterprises for years to come.

## ACKNOWLEDGEMENTS

We would like to thank Dr. Larry N. Bohs, our professor, for providing us with this design opportunity and aiding us in the design process. Jeremy Dahl, our Teaching Assistant, aided in electrical troubleshooting. We'd also like to acknowledge Joe Owen, who machined the enclosure, and Antonia Pedroza and Judy Stroup for Orange Enterprises, who both advised us on device characteristics.

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# THE TASK CUEING TIMER

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## ABSTRACT

Our client is a man with autism and relies on supervisors to enforce task durations and schedule. We sought to design a device that limits this supervision. The Task Cueing Timer (TCT) uses visual, auditory, and tactile stimuli to cue our client of starting and stopping times for a task. A progression of colored, blinking lights helps him to anticipate the end of his activities. *Start*, *Finish*, and *Reward* windows provide additional visual cueing. An audible buzzer and vibrating wristband expand the device's use. We expect that the TCT will help supply our client with a clear understanding of his task beginnings, their completions, and his next activity, helping him to more independently perform his daily routine.

## BACKGROUND

Our client is a 31-year old male with autism. He is often unresponsive to surrounding stimuli and requires constant alerting of his daily tasks. The client is also affected by CHARGE syndrome, a disorder that results in certain physical disabilities. He has deafness and visual impairments, seeing primarily with his left eye. His reading capabilities are limited to simple words and he responds primarily to bright colors and lights.

The client is responsible for tasks with and without time limits. His disability however, results in an inability to properly track the amount of time he spends during these activities. He presently receives abrupt cues from his supervisors that often make him uncomfortable. The TCT will help him to recognize the duration of his tasks, allowing him to anticipate stopping times, and thus reducing the need for such alerts.

For people with visual and auditory disabilities, cueing is often performed via vibrations. However, our client is tactile defensive and as a result, other cueing methods are needed. Our client responds best to visual stimuli. Current visual cueing products are designed mainly to keep the attention of the user. Some provide accurate representations of time durations as well. However, we have found no products that specify what is to be done once the time limit is complete. Our device fulfills this need, and more importantly, is designed specifically for our client.

## PROBLEM STATEMENT

The main goal of our device is to effectively time our client's daily activities and allow anticipation of task transitions. Because of our client's disabilities and preferences, the primary cueing methods are visual. The device is portable and lightweight so that our client may use it at home and at work. Portability increases the chance that the device will be dropped; therefore, the device must be durable. Finally, audible and tactile cues are desired, so that others with similar task cueing needs can use the device.

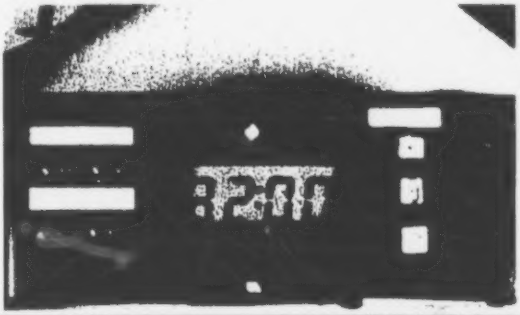
## RATIONALE

There are three main needs our client posses. First, he wants to move in between tasks independent of cueing from his supervisors. Second, he wants to feel comfortable when making these transitions. Finally, he needs to be alerted as to what his next activity must be. The TCT provides solutions for these three needs by allowing our client to move independently and comfortably between tasks, and correctly informing our client of his next activity.

## DESIGN AND DEVELOPMENT

There are two main parts of the TCT. The first part is the user interface. This functions as the control panel for the timing and cueing mechanisms of the TCT. The visual stimuli of the front display and the additional audible and tactile cues compose the second part. The design process will be explained in terms of these two main components.

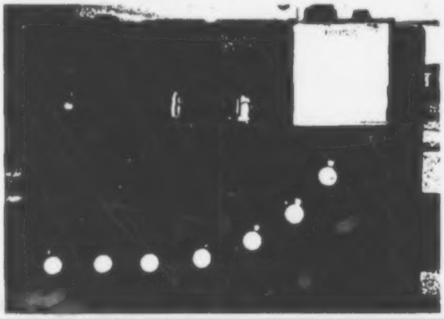
Figure 1: User Interface



The user interface was designed to provide a means for setting and clearing the countdown time, as well as starting and stopping the device itself. After an initial meeting with our client's supervisors, the requirements of the timing functions were determined. The resulting user interface is shown in Figure 1.

The power switch controls battery flow to the device. The countdown time can be viewed on the 4-digit 7-segment liquid crystal display. The time duration of the activity can be set using the "+1" and "+5" buttons, increasing the time by 1 and 5 minutes, respectively. The "Start/Stop" button activates the countdown and can also be used to pause it. Three "Cue Toggle" buttons independently control power to each cue, allowing adjustment based on user preference.

Figure 2: Visual Display



Design of the visual cueing component required slightly more experimentation than the user interface design. It required finding a stimulus that would keep the client's attention while not distracting him from his activities. Our supervisors deemed an initial design involving a rotating picture to be unnecessary and possibly distracting. After another meeting with the client, the final design was chosen. A later client meeting helped to determine the proper LEDs for the visual cues.

The final visual design incorporating our client's input is shown in Figure 2. It entails a progressive string of large LEDs that slowly approach the "reward window" (upper right) as time progresses. At task completion, an illuminated slide in this window cues our client to his next activity. Our client is familiar with the slides used, and thus, our design allows easy incorporation into his routines. Illuminated start and finish windows reinforce the beginning and ending of the time durations.

Further features were added to increase comfort and usability. An adjustable stand allows for the TCT to be positioned at an appropriate viewing angle, either on a table top or over the back of a chair, and a carrying strap allows for easy portability. Finally, rechargeable NiMH batteries were used for long battery life and low maintenance. The batteries are charged via an external charger, which plugs into the TCT when not being used.

## EVALUATION

The TCT has been tested in a number of different ways throughout the course the design process. Portability and weight constraints were checked early on in the process by presenting the enclosure and other component choices to our supervisors for feedback. Blinking lights were tested with our client early on, to which he appeared very attentive.

With regards to device operation, expected battery life was estimated based on nominal current draw of all circuit components. Actual battery life was then tested prior to delivery to ensure life of at least 8 hours before recharging. Timer accuracy was tested and confirmed to be accurate to within one second for periods up to 60 minutes.

## DISCUSSION AND CONCLUSIONS

All objectives were achieved with our device design. It is the nature of our device that the client must learn to incorporate it into his routine. However, our supervisor ensured us that he is capable of doing so. Furthermore, the incorporation of auditory and tactile cues extend the possibility of its use to others who may benefit.

## ACKNOWLEDGEMENTS

We would like to thank our professor Larry Bohs for his guidance throughout the semester. Greg Beck, Jen Bell, Gina Chapman, and our client's parents were an integral part of the design process. We thank Jeremy Dahl, Joe Owen, and our classmates for technical assistance and advice.

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# Augmentative and Alternative Communication
## (Topic 2)

# CONTINUOUS KOREAN SIGN LANGUAGE RECOGNITION USING GESTURE SEGMENTATION AND HIDDEN MARKOV MODEL

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## ABSTRACT

In recognizing gesture words such as Korean Sign Language (KSL), it is a very difficult to segment a continuous sign into individual sign words since the patterns are very complicated and diverse. To solve this problem, we disassemble the KSL into hand motion classes according to their patterns. Observing the speed and the change of speed of hand motion and using state automata, we reject unintentional gesture motions such as preparatory motion and meaningless movement between sign words. To recognize hand motion classes we adopt Hidden Markov Model. Using these methods, we recognize 10 KSL sentences and obtain 95% recognition ratio.

## BACKGROUND

Sign language is a representative example of hand gesture with linguistic structure and is important for the hearing impaired to communicate one another. It is, however, required to develop a system capable of recognizing and/or generating sign language, in order to communicate with normal person.

Sign language recognition has been attempted since several years. Starner [1] proposed a HMM-based recognition algorithm with his vision system. It recognizes 40 words with 91.3% accuracy. Liang proposed a glove-based system, which can recognize Taiwanese Sign Language [3]. This HMM-based system recognizes 250 words with 90.5% accuracy. Kim et al. used Fuzzy Min-Max Neural Network to recognize Korean Sign Language (KSL) [2]. It recognizes 131 words with 94.3% accuracy based on 14 hand motion-direction classes, 23 hand posture classes, and 14 hand orientation classes. However, these systems concentrates on a part of sign language that has hand trajectory using glove device [1-3].

This paper presents a vision-based recognition system of continuous KSL as shown in Figure 1. For this end, it is first necessary to segment a continuous motion gestures into isolated basic forms, and then the isolated words are recognized.

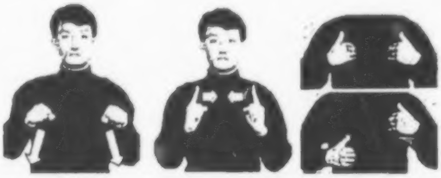


Figure 1. Continuous KSL sentence: "Hello, nice to meet you."

## METHOD 1: GESTURE SEGMENTATION

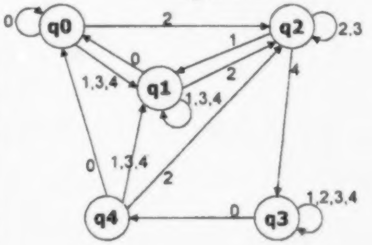
There are no explicit indications for the beginning and the end of gesture. So, the meaningless movement that changes hand position to prepare next gesture can be interpreted as a meaningful sign word. By analyzing hand motions, we can observe that the speed and the change of speed of hand motion can be used as remarkable features. For an example, meaningful sign words consist of three distinct phases: preparation, stroke and end, while meaningless gestures do not have distinct stroke.

From the feature pair, we can define 5 motion phases (stop, preparation, stroke, moving and end) and develop 6 rules based on the phase patterns. Then, the rules are adopted to discriminate meaningless gestures and segment the continuous KSL sentence into several isolated words in the framework of state automata as shown in Figure 2.

Table 1. The defined states of automata for continuous KSL

| State | Description | Function |
|---|---|---|
| $q_0$ | Resting state | Initialization<br>Static gesture recognition |
| $q_1$ | Preparation state | Initialization |
| $q_2$ | Stroke/ Moving state | Feature extraction |
| $q_3$ | Ending/ Repetition state | Feature extraction |
| $q_4$ | End state | Dynamic gesture recognition<br>Initialization |

Fig. 2. State automata diagram for gesture segmentation.



In this figure, $q_0$, $q_1$, $q_2$, $q_3$ and $q_4$ mean 5 states, which are defined in Table 1, and arrows mean state transition functions and numbers on the arrow mean 5 motion phases such as 'stop', 'preparation', 'stroke', 'moving' and 'end' respectively, which are labeled as 0,1,2,3,4 respectively.

Generally meaningful sign word starts in state q0 and ends in state q4 after several state transitions. Whereas, meaningless gesture starting in state q0 cannot reach state q4. The result of the automata based gesture segmentation is the set of isolated words.

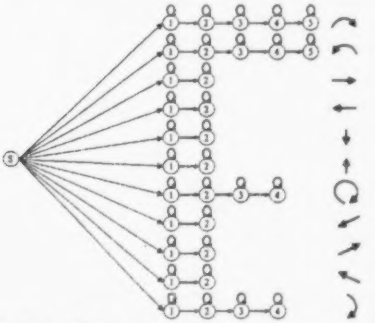


Figure 3. The HMM network for gesture recognition

## METHOD 2: GESTURE RECOGNITION

To recognize isolated words, we define 11 hand motion classes depending on motion features, and adopt Hidden Markov Model (HMM), which is effective to model spatio-temporal information. The HMM is a collection of states connected by transitions. Each transition has a pair of probabilities: a state transition probability and an output probability, which defines the conditional probability of emitting an output symbol from given state [4].

Because we use discrete HMM, the feature of hand motion has to have discrete values. The hand motion can be expressed as the set of direction feature. All motions at every sample steps are quantized into 16 directions. Here we do not consider the distance of motion at each sample step.

We have already segmented the continuous hand motion into isolated words, so we only need to recognize the hand motion of isolated word. To do so, we have constructed left-right type HMM network for gesture recognition as shown in Figure 3 because the direction sequence has clear start point and end point. In the figure, S is the dummy start state and 11 arrowed motions in the right side mean 11 hand motion classes. With the HMM network for gesture recognition, we discriminate the class of the segmented gesture. We select the likelihood model that has the biggest probability on each class.

## RESULTS

To verify the proposed vision-based KSL recognition system, we have implemented the algorithm on 500 MHz Pentium PC with Matrox Genesis imaging board and PULNIX TMC-7 RGB camera. We have obtained very successful experimental results with 95% accuracy of recognition in hand motion classification.

## DISCUSSION

Continuous sign language is not simply connected form of individual sign words. They entail meaningless gestures, which make machine recognition difficult. This paper studied segmentation and recognition of continuous sign language using color vision. We have used the state automata method whose inputs are defined as the speed and change of speed of motion to segment isolated sign words from continuous sign language. And we adopted HMM method to recognize hand motion, since the method is effective on spatio-temporal data and is effective to recognize continuous Korean Sign Language.

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# A LANGUAGE ACTIVITY MONITOR FOR DIGITIZED SPEECH AAC SYSTEMS TO SUPPORT EVIDENCE-BASED CLINICAL PRACTICE AND OUTCOMES MEASUREMENT

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## ABSTRACT

AAC evidence-based practice requires the use of instrumentation to collect data and measure outcomes (1). The work on automated data logging and the language activity monitor has been based on the availability of a textual representation of the language activity, such as is common with text-to-speech based systems. However, many AAC devices utilize digitized speech and thus have no textual form of the language activity. This project explored the feasibility of the notion of LAM for use with digitized speech AAC devices. The Digitized LAM (DLAM) records the speech output of these devices. The data, which includes time-stamps and encoded audio, can later be converted to LAM format on a computer and then analyzed like LAM data.

## BACKGROUND

Augmentative and alternative communication (AAC) evidence-based practice and outcomes measurement emphasize the need for systematic clinical data collection by teams to support clinical decisions (2). Systematic data collection should include objective measures of system performance by consumers. Some of the most valuable objective language measures document performance gathered from language sampling. The development of the language activity monitor (LAM) has facilitated language sampling (3). Objective non-language measures involve identifying variables related to the human-device interface such as access and rate. Objective language and non-language measures have been reported using automated data logging from LAM (4). However, current tools and methods involving automated data logging have been developed only for AAC synthesized speech systems. Consequently, AAC performance data collection for individuals who rely on digitized systems requires traditional time consuming methods of observation and recording.

## STATEMENT OF THE PROBLEM

Traditional methods of monitoring AAC digitized speech system performance are based on clinical observation and video or audio recording with subsequent observation, timing and/or transcription. With the clinical implementation of LAM for AAC synthesized speech systems, the need to develop tools to support automated data logging for digitized speech systems became obvious.

## RATIONALE

The DLAM development was aimed at providing tools for data collection and analysis from the speech output of digitized AAC devices. These tools were designed to provide an easy and accurate method to collect field data on numerous AAC products currently available from various AAC device manufacturers.

## DESIGN

The design was a team effort, including a focus group representing professionals and consumers with clinical speech-language pathology (SLP), special education, research, and technical expertise. Design features of the DLAM that were identified initially included:

- Device compatibility with most digitized AAC products
- Compact flash card to facilitate data storage and memory transfer to a PC
- Internal speaker and external speaker jack for audio interface
- Internal microphone to record an audio cue identifying user or other clinical data
- Real time clock for data time stamp with 1 second resolution
- User interface for record/playback, card storage capacity and other system information
- Compact packaging with rechargeable batteries to accommodate daily use

DLAM functions including the user interface were initially simulated on the PC to refine the physical layout, record/playback functions and other features. Recording routines, system information enunciation, file functions and driver interfaces were developed concurrently with the hardware development.

The DLAM audio input circuit was designed to capture, as accurately as possible, the digitized messages that are reproduced by the various communication devices. This necessitated a connection to the external speaker jack, not a microphone, to eliminate all ambient noise.

## DEVELOPMENT

The core components of the DLAM include the WinCE operating system and Intel's StrongARM 32-bit RISC (reduced instruction set computer) processor, SA1110. Using WinCE with the ARM technology provided a standard operating system with high-performance processing and low-power consumption. This implementation supports the ATA compact flash card, 16MB of flash memory, 32MB DRAM and FPGA (field programmable gate array) interfaces.

To minimize interface circuitry for the memory card, real time clock, tone circuitry and other peripherals, a FPGA was implemented. Rechargeable Li-ion batteries were also used in the device because of their high energy density and discharge characteristics. Battery voltage sensing circuitry was implemented to estimate the remaining battery capacity.

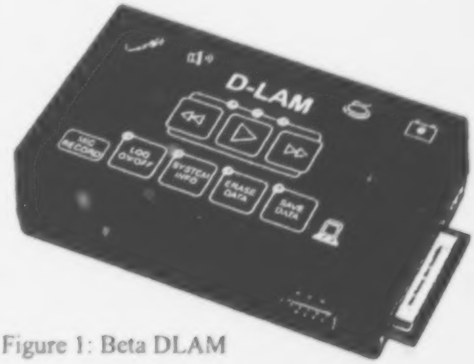

Figure 1: Beta DLAM

The beta DLAMs were packaged in a standard case (FIGURE 1) with the dimensions of 2¾" x 4¾" x 1½". All user interface functions are located on the top of the device. The compact flash card, switch interface, external speaker connector and serial connector are on the periphery.

DLAMterm is a Windows based software tool developed for the PC to retrieve the DLAM data and transcribe the recorded language samples. Using this tool, it is possible to upload DLAM data to a PC, copy saved data from a DLAM memory card onto a PC, and transcribe the recorded data into a text format compatible with language analysis software.

This transcription process in the DLAMterm allows the user to step through the recorded data, one utterance at a time, listen to the utterances, and enter text representing each utterance. A progress indicator, auto-text completion and other user-friendly features implemented in DLAMterm simplify the transcription process.

## EVALUATION

The initial phase of this project involved testing the feasibility of the DLAM under laboratory conditions as well as conducting a reliability study of the transcription process. In addition, the study involved beta testing under normal conditions, and consisted of ten field sites located in the following states: Florida, Louisiana, Mississippi, New Jersey, New York, Ohio, Pennsylvania, and Virginia. Field testers involved clinicians working in public schools, rehabilitation centers, developmental centers, and universities.

## DISCUSSION

The laboratory and field testing results demonstrated the feasibility of the technology of a language activity monitor for digitized speech AAC systems in that encoded audio signals with time stamps can be converted into text. Experience from the first phase of this project was gained to improve the future direction of the design and provided useful information in planning for the next phase. Valuable feedback regarding the design features of the DLAM was received from the field testers. The use of the flash card posed challenges to the clinicians. The feedback has resulted in significant simplification of the system controls and redesign of the DLAM device. In addition, feedback encouraged development of the DLAM as an internal function, since field testers had experience with the LAM as a built-in function in synthesized speech AAC devices. The field testers overwhelming value the concept of language activity monitoring and are eager to participate in future work. These tools allow for the collection of data in accordance with the principles of evidence-based practice.

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# THE LEARNING EXPERIENCES OF AAC USERS: RESULTS OF AN INTERNET-BASED FOCUS GROUP DISCUSSION

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## ABSTRACT

A focus group discussion was conducted on the Internet to investigate the augmentative and alternative communication (AAC) learning experiences of seven individuals who use AAC. Information was gathered in the following areas: (a) issues in the selection of an AAC device; (b) knowledge needed to make competent use of an AAC system; (c) activities used to gain proficiency in the use of an AAC system; and (d) indicators of progress/success in learning to make use of an AAC device. Factors described as important to the participants' learning of an AAC device included: personal motivation to master the use of the device; active and informed participation in the device selection process; opportunities for well-organized instruction and independent practice; positive feedback from communication partners; and the opportunity to observe proficient AAC users.

## BACKGROUND

At present, we have only a limited understanding of the factors that serve as supports and barriers to learning to make efficient use of an AAC system (1). A better understanding of factors contributing to successful learning experiences is critical to the development of assistive technology that will meet the needs of AAC users. One important source of information is AAC users themselves, who have first-hand experience in learning to make effective use of AAC systems.

## RESEARCH QUESTION

This study investigated the AAC learning experiences of seven individuals with cerebral palsy who use AAC. More specifically, the study investigated four areas: (a) issues in the selection of an AAC device; (b) knowledge needed to make competent use of an AAC system; (c) activities used to gain proficiency in the use of an AAC system; and (d) indicators of progress/success in learning to make use of an AAC device.

## METHOD

The study employed a qualitative research design involving the use of a focus group, conducted via the internet. All participants had a diagnosis of cerebral palsy, were competent users of AAC technology, and had successfully completed high school. Seven participants were involved in the study, four women and three men, ranging in age from 21 to 35 years old. The participants had used a variety of both "high-tech" and "low-tech" AAC systems; all participants had learned and made use of at least three different devices prior to their participation this discussion.

The research questions for this project were generated by a team of researchers that included two individuals who use AAC (TR and MW) as well as two individuals who do not use AAC (CK and DM). The first author (TR) served as the moderator of the focus group and was responsible for presenting the discussion topics, encouraging dialogue, and regulating the discussions as needed (i.e., redirecting the discussions, requesting participation).

The focus-group was held at a password protected website using a "guestbook" software entitled Phorum-3.2.5 (2). Guestbook software allows text-based discussions of multiple topics among several individuals using the Internet. The participants were asked to visit the Internet site at least three times each week, and respond to the questions posted by the moderator as well as to the contributions of the other members of the focus group. The focus group continued for a 6-week period. During this time the participants posted 120 messages, a total of over 12,000 words. Prior to the data analysis process, data were saved from the web site to a word-processing document. Analysis procedures then followed a five- step process (3). The final coding themes included: (a) issues in the selection of a device; (b) the knowledge needed to make competent use of an AAC system; (c) the activities used to gain proficiency in the use of an AAC system; and (d) the indicators of progress/success in learning to make use of an AAC device.

## RESULTS AND DISCUSSION

This section presents the findings of the study and discusses these findings as they relate to each of the four main coding themes.

Issues in the selection of an AAC device. Participants described both positive and negative experiences in the selection of their AAC device. Some users reported that they were in charge of the decision and were able to obtain the knowledge they needed to make an informed decision. Others experienced significant difficulty in getting needed information, and therefore received inadequate and inappropriate services.

Participants spoke of the importance of internet technology in the device selection process, especially opportunities for discussion with other AAC users via email. For some of the participants in this group, however, lack of access to needed information, and a lack of expectation that the user of the device should play an important role in the selection of the device, hampered meaningful participation in the assessment and device selection process.

Knowledge needed to make competent use of an AAC system. Participants identified skills in four major areas that were needed to make effective use of an AAC system (4): (a) operational competence, which included learning how to operate and program the device, as well as learning how to deal with breakdowns in technology; (b) linguistic competence, which included the skills necessary for selecting vocabulary for storage in the device, as well as knowing how to organize and (as necessary) encode the vocabulary; (c) social competence, the ability to put partners "at ease" with the AAC device; and (d) strategic competence, knowing how to use a variety of modalities, as needed, and how to deal with break-downs in conversations.

There was considerable individual variation both in the time needed to learn these skills, especially learning to organize and encode vocabulary. Dealing with technology breakdowns posed the greatest challenge; when a device breakdown occurred, participants lost the technique which best enabled them to explain what had gone wrong with their technology.

Activities used to gain proficiency in the use of an AAC device. The participants in this project made use of a wide variety of activities to gain proficiency in the use of their device, including self-instruction and independent practice; instruction from others, including manufacturer's representatives and speech-language pathologists; and learning from other AAC users. Some participants demonstrated considerable perseverance in learning to master their systems; one participant described "studying 3-4 times a week for two hours at a time…it took me about two years to learn the vocabulary really well". Many participants spoke of their difficulty in finding trained personnel to assist them in learning to make effective use of their devices. Participants expressed interest in ways that internet technology could assist in training activities, perhaps in part because of their difficulty in finding "live" assistance.

Indications of progress in learning to make use of an AAC device. Participants discussed a wide variety of topics related to evaluation of progress, including their perceptions of the reactions of others to their use of the device, as well as their perceptions concerning the relative ease in learning to make use of a device. For some participants, negative feedback from members in the community served to discourage device use - other participants spoke of their efforts to ensure that their messages were clearly understood regardless of the communication partner's initial reaction.

## SUMMARY

Common to many of the participants was their identification of ambitious goals for their personal use of AAC systems, and their interest in being active participants in the learning process both by seeking out instruction, and by developing independent practice activities. Directions for technology development identified by the participants included the investigation of ways in which AAC devices could be made both more durable and more rapidly repaired, and ways in which internet technology could serve in the device selection and training process.

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# ACQUISITION OF SCANNING SKILLS: THE USE OF AN ADAPTIVE SCANNING DELAY ALGORITHM ACROSS FOUR SCANNING DISPLAYS

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## ABSTRACT

This study examined the effects of an adaptive scanning delay algorithm on the single-switch scanning performance of 15 participants using four different types of scanning displays (word prediction, character prediction, ambiguous keyboard, and frequency-optimized row-column scan). Participants using the word prediction scanning array achieved the highest character production rate, while subjects using the ambiguous display achieved the lowest production rate.

## BACKGROUND

For people with severe disabilities, row-column scanning displays may be the only viable option for communication. Many researchers have proposed methods to accelerate scanning input by improving the efficiency of each switch activation. While some of these methods indisputably provide significant switch savings, very few have been empirically tested to determine their effects on communication rate. In the few instances where they have been tested, there is some evidence that the attentional loads associated with the methods may overpower the switch savings, resulting in a net decrease in communication rate (Koester & Levine, 1994).

In an earlier study (Lesher, Moulton & Higginbotham, 1998) we surveyed techniques for augmenting scanning communication. We found that by adding a six-word prediction list to a scanning array, up to 31% fewer switch activations are necessary to produce a given message (when compared to scanning with a frequency-optimized row-column array). If the word list is replaced by a six-character prediction list, up to 33% fewer activations are required.

The efficiency of scanning selections can also be improved by changing the nature of the scanning array itself. By replacing the standard array with an ambiguous keypad with a smaller number of keys (like a telephone keypad), the average number of switches necessary to scan to each key decreases. Switch savings of up to 15% are achievable when this scheme is combined with a disambiguation algorithm that can accurately "guess" which letters the user intended.

The switch savings of the techniques described above were evaluated using an autonomous testing program. To assess their effect on human communication rate, we designed and implemented a cross-technique comparison of the three augmentative techniques, using a standard row-column scanning array as a control.

## METHOD

Fifteen able-bodied students at University at Buffalo participated in this study. Students were randomly assigned to one of three scanning display conditions. Each student learned to operate an experimental scanning display (word prediction, character prediction, ambiguous keyboard) and a control display (frequency-optimized letter array), all as defined in Lesher et al. (1998). During training and the experiment, participants used the displays to alternately copy paragraphs of text and answer non-personal questions. The transcription materials were randomly selected from a large database of testing texts.

Participants interacted with Pentium II computers running the Linux operating system. Our IMPACT software ran the scanning displays and automatically recorded the subject selections for subsequent analysis. Participants wore headphones and were provided with audio feedback in the form of a soft beep to indicate every scanning group advance. Selections were made by clicking a mouse button.

During the experiment, the scanning delays were adjusted automatically using an algorithm developed for this study (Lesher, Higginbotham, & Moulton, 2000). Delays were gradually decreased when subjects exhibited error-free performance and rapid selections, and slowly increased when the subjects overscanned the targets or deleted mistaken selections. For each display, participants received 2 hours of training before the adaptive delay was initiated. Subsequently, participants used each display for 15 hours. Each session lasted for approximately 2 hours.

Individual trials were averaged across each hour for each participant, then averaged by experimental group. Descriptive analyses are provided for the resulting acquisition curves (Figure 1). A Tukey multiple comparison procedure was conducted on the last 5 hours of each experimental condition to determine the presence of significant differences for character production rate, error rate, delay time, and selections per character. Statistical analyses focused on comparisons between the experimental interfaces and with each row-column display control, resulting in a family-wise error rate of $p<0.05$.

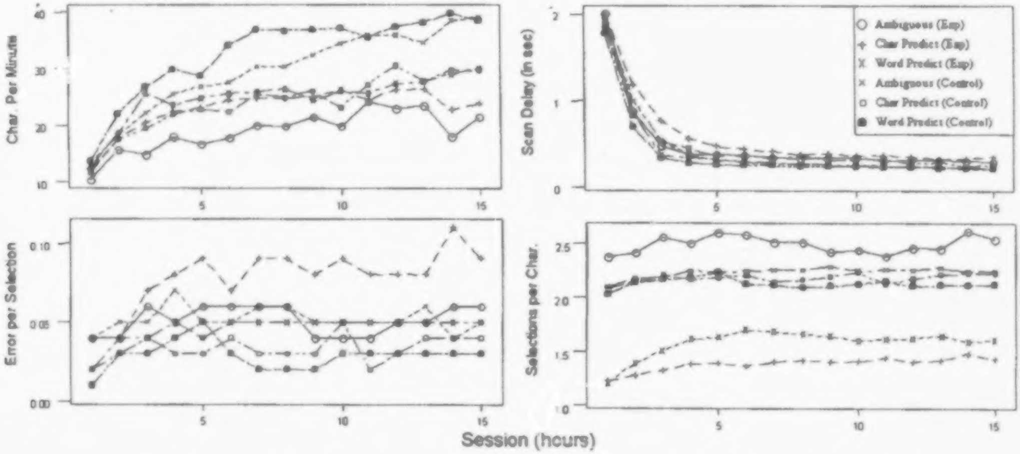

**Figure 1:** Acquisition curves for experimental conditions and control.

## RESULTS

Character production rates over the 15 hours of each experimental condition revealed rapid rate increases for word prediction and its control. This contrasts with a noticeably flatter slope for the other displays. In particular, the ambiguous display barely achieved 20 characters per minute (cpm) over the last hours. The average character per minute production rate for word prediction (36.9 cpm) substantially outpaced both character prediction (24.8 cpm) and the ambiguous display (22.1 cpm). The latter displays were both significantly slower than their row-column control displays (ambiguous = 28.0 cpm, character = 29.1 cpm).

The graph of scanning delays depicts a steep decrease in delays during the first 5 hours of use for all displays except for character prediction, which evinced a much flatter rate of change. Scan delays for the character prediction display were significantly longer than those for the ambiguous display, which in turn were longer than those for word prediction. Only character prediction yielded significantly longer delays than its row-column control.

Error rates increased during the first 4 or 5 hours for the experimental display interfaces, but not for their controls. The controls, on average, showed the lowest error rates. Error rates for character prediction exceeded all other displays after hour 3 of the experiment, with approximately double the rate of the other displays, which were statistically equivalent to one another. All experimental displays produced significantly more errors than their controls.

Character selection efficiency remained fairly stable across the experiment. Selection efficiencies for the control displays were uniform across time. Efficiency decreased slightly (upward trend) for word prediction during the first few hours of the experiment. On average, the ambiguous display yielded more selections per character (2.48) than word prediction (1.61), which in turn yielded more than character prediction (1.43). The ambiguous display was also less efficient than its control. The reverse was true for the other 2 displays.

## DISCUSSION

Of the three augmentative techniques evaluated, only the word prediction display provided a higher communication rate than its row-column control display. Scanning delays, which were updated automatically to maximize rate, were approximately the same for all conditions. Since the three experimental conditions all required significantly fewer switch activations to produce a given message, the slower communication rate implies that error rates were higher and more costly for character prediction and the ambiguous display than for their controls. Although this study failed to show the rate benefits for these two techniques, Figure 1 indicates that learning is still occurring after 15 hours of trials – rate gains could conceivably be realized with additional training. In addition, significant reductions in the required number of switches may reduce user fatigue.

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# RELIABILITY STUDY OF LANGUAGE SAMPLES USING SOFTWARE TO SUPPORT THE TRANSCRIPTION OF DIGITIZED SPEECH AAC SYSTEMS.

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## ABSTRACT

This study was part of the design and development phase for a digitized speech language activity monitor (DLAM). This task looked at the reliability of converting the WAVfile logfiles into text using software developed specifically for the DLAM to facilitate the transcription process. Twelve transcribers were assigned to correctly upload, transcribe, code, and analyze DLAM logfiles. Transcribers were required to achieve intra-rater reliability of 95% before handling the research data. Inter-rater reliability for utterance segmentation, word-by-word agreement, and the identification of pre-stored messages was determined. Reliability results ranged from 93% to 100% for the identified summary measures.

## BACKGROUND

Principles of evidence-based practice and outcomes measurement emphasize the need to use instrumentation to collect data to support clinical decision-making and evaluate intervention services. With the shift toward accountability, developing tools to support data collection as well as integrating them across service delivery sectors and geographic borders would have a tremendous impact on outcomes measurement (1). The development of automated logfiles (2) and the AAC language activity monitor (LAM) (3) for clinical use has made available quantitative data on which to base intervention decisions. The LAM has made possible various analyses of data that can prove useful to clinicians as well as to people who rely on AAC. Analysis of AAC language samples collected using LAM has provided information similar to that available from samples of speaking individuals. Research using LAM logfiles has reported inter-rater reliability of the transcription process for utterance segmentation and word-by-word agreement at 96% and 100% respectively (4).

The majority of AAC devices in use today are digitized speech systems that do not have serial output capabilities. The DLAM records the speech output of these devices. The information, which includes time-stamps, can be uploaded to a computer and later analyzed for data to support AAC evidence-based practice.

## RESEARCH QUESTION

This study was designed to determine the reliability of the transcription of digitized language samples using the DLAM Term PC software. In order for logfiles to be analyzed and used as data to report summary measures, the logfiles must be edited and coded as transcripts. Logfiles from digitized speech AAC devices must be converted from WAVfiles into text as part of the transcription process. The reliability of this transcription process has never been evaluated.

## METHOD

Language samples were generated on a digitized speech AAC system. Ten utterance test lists were generated and these lists comprised the controlled sample. Some of the considerations in constructing the DLAM utterance test lists included the following: 1) previous research on language sample data collected using LAM tools and 2) vocabulary and customized utterances using the Unity 32 on the AlphaTalker. The demands on transcription were increased by varying the selection rate when the lists were generated.

Twelve transcribers were assigned to upload, transcribe, code, and analyze the control samples. These individuals consisted of six undergraduate and graduate students in speech pathology, three trained speech–language pathologists, and three professionals with computer experience. The individuals received 1:1 or 1:2 group training that lasted approximately one hour along with the transcription-training manual to follow for practice. All the transcribers were blind to the research questions.

A point-by point agreement of 95% initial intra-rater reliability was achieved using training lists before the actual transcription process was commenced. Reliability was calculated as percentage of agreements/(agreements+disagreements) for each rater for each sample.

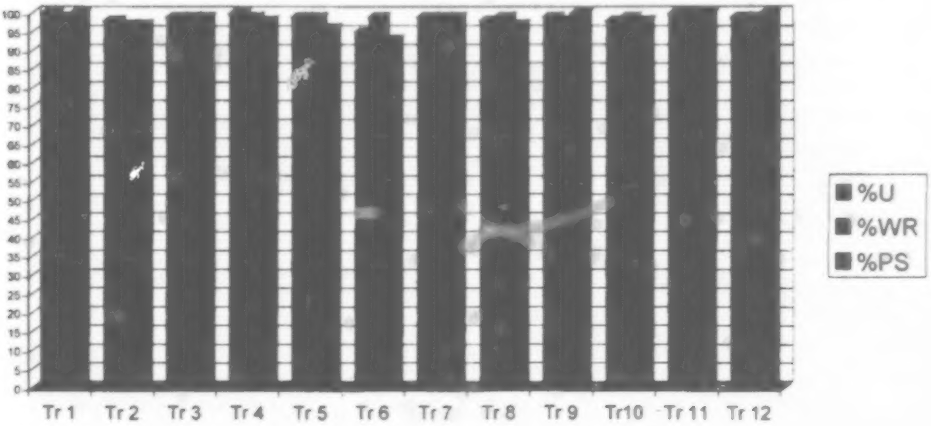
Each individual was required to transcribe each utterance list twice making a total of 120 language samples used to calculate the reliability. The ten lists were randomly selected for transcription. The transcription process was two fold in nature. The first step involved using the DLAM Term PC software to listen to a DLAM logfile and transcribe the auditory signal thereby creating a text file which was a written representation of the digitized language sample. Once the utterances were transcribed, the transcribers needed to review the time stamps and text to identify and report the summary measures used to determine reliability.

The transcripts were examined for reliability in the following three areas: 1) ability to transcribe the words correctly (Word recognition); 2) ability to segment the time stamps and text into utterances (Utterance segmentation); and 3) ability to identify (code) pre-stored utterances.

## RESULTS

Table one shows the mean reliability on the three measures for the twelve transcribers

Inter Transcriber Mean Reliability



U=utterance; WR=word recognition; PS=pre-stored messages

The average percentage of agreements on utterance segmentation was found to be 98.67%(range of 98 to 100). The inter-rater reliability for word-by word agreement was found to be

98.83% (range =97 to 100%). The inter-rater reliability for the identification of pre-stored messages (code agreement) was found to be 98.0% (range was 93 to 100%).

## DISCUSSION

The study shows that there is strong inter-rater reliability for transcribing digitized speech-language samples using the DLAM Term PC software. The high reliability that occurred using controlled samples under laboratory conditions would not be expected to be representative of performing transcription under normal conditions. However these reliability results clearly indicate the feasibility of using the DLAM PC software as a clinical transcription tool for collecting language samples using digitized speech AAC systems. Since the feasibility study demonstrated that WAVfiles can be converted into text, a whole range of computerized language analysis tools become available to report a variety of clinically useful summary measures on individuals who rely on digitized speech AAC systems. Further research investigating the reliability of transcription under normal training and working conditions is suggested.

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# THE AAC RATE INDEX IN CLINICAL PRACTICE

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## ABSTRACT

AAC evidence-based clinical practice requires data collection and outcomes measurement. Recent advances in methods and tools to support evidence-based practice facilitate the generation of a communication performance summary measure report. One of the identified summary measures possible using automated data logging is the rate index. The rate index has been defined to separate the selection rate from other factors influencing communication rate. This study reports preliminary results from collecting language samples from five individuals who rely on AAC systems and reporting the rate index.

## BACKGROUND

For people who rely on AAC, speech-language pathologists (SLPs) are now expected to provide services in accordance with the principles of evidence-based practice (1). Automated tools and methods are available to support data collection and outcomes measurement (2). Summary measures of communication performance include communication rate in words per minute (3). Factors that influence communication rate include the selection rate (bits per second) (4), use of language representation methods, and errors (5).

The *rate index* is a communication performance summary measure that is calculated by dividing the communication rate in words per minute by the selection rate in bits per second and dividing the result by 60 seconds per minute (6). Thus the unit of measure for the rate index is words per bit. The rate index then is a measure of communication performance that is independent of the selection rate. Rate index provides for the comparison of communication rates adjusted for differences in selection rates. Rate index comparisons can be made between individuals using similar or different systems or for one individual under different conditions.

A first step in the evidence-based therapy process is characterizing the individual and determining the level of performance that would constitute the desired communication performance for that individual. Next the collection and analysis of language samples from the individual form the basis of current and past performance. Finally the current performance is compared to desired performance and to past performance to drive the therapy program. Rate index may serve as a summary to facilitate clinical decision making and make comparisons between different user profiles.

## RESEARCH QUESTIONS

Can the AAC rate index be a clinically useful summary measure? What factors influence the calculation of the rate index? Is rate index consistent across language sampling contexts?

## METHOD

Using automated language activity monitoring, language samples were collected from five subjects who participated in a controlled study. All subjects were individuals who rely on AAC systems. The five individuals ranged in age from 18-48, had cerebral palsy, and used an AAC device with synthetic speech output that allowed for the use of the three-language representation methods: single meaning pictures, alphabet based methods, and semantic compaction. Four subjects accessed the AAC keyboard using unassisted direct selection. One subject used optical headpointing. All subjects reported that they considered themselves competent communicators. Table 1 shows background information on the five subjects. Language samples were collected in two contexts, an interview and a picture description task.

Table1. Background information on augmented communicators

| **Subject** | **Age** | **AAC System** | **Array size** | **Selection Method** |
|---|---|---|---|---|
| 1 | 48 | Words Strategy/Liberator | 128 | Unassisted Direct |
| 2 | 21 | Words Strategy/Liberator | 128 | Optical Head Pointing |
| 3 | 18 | Unity/Pathfinder | 128 | Unassisted Direct |
| 4 | 45 | Unity/Deltatalker | 128 | Unassisted Direct |
| 5 | 36 | Custom/Vanguard | 45 | Unassisted Direct |

**RESULTS**

The analysis of the collected language samples included the calculation of communication rate, selection rate, and rate index. Table 2 shows these results for the five subjects in the study for each of the two language sampling contexts.

Table 2: Communication rate, selection rate, and rate index for five subjects.

| | Interview | | | Picture Description | | |
|---|---|---|---|---|---|---|
| Subject | Comm. Rate | Sel. Rate | Rate Index | Comm. Rate | Sel. Rate | Rate Index |
| | (words/min.) | (bits/sec.) | (words/bit) | (words/min.) | (bits/sec.) | (words/bit) |
| 1 | 14.8 | 12.39 | 0.0199 | 13.0 | 12.04 | 0.0180 |
| 2 | 6.5 | 7.00 | 0.0155 | 5.3 | 2.60 | 0.0340 |
| 3 | 10.9 | 24.61 | 0.0074 | 10.3 | 22.14 | 0.0078 |
| 4 | 11.4 | 7.61 | 0.0250 | 11.8 | 21.00 | 0.0094 |
| 5 | 16.6 | 8.75 | 0.0316 | 14.0 | 8.40 | 0.0278 |

**DISCUSSION**

While selection rate can be addressed in AAC therapy, most therapy time is used to work on other issues. Without consideration for differences in selection rate, communication rate comparison between individuals can be meaningless. What was needed was a communication performance summary measure that normalizes the impact of selection rate.

Selection rate for an individual can change from time to time. In the short term, selection rate can be a function of general energy level, positioning, fatigue, medication, and other like factors. In the longer term, selection rate can change as a result of efforts to optimize physical access, progression of a condition, etc. However, selection rates that are calculated from language samples taken in close proximity could be expected to be comparable.

For all subjects, the two language samples were collected in close proximity. For both Subject 2 and Subject 4, the reported selection rates for the two contexts were significantly different. A review of the data used to calculate these revealed that spelled words (the basis of selection rate calculation) that are short can produce outliers in the data. This is because the resolution of the time stamp is only one second. A suggested solution to this is to base the selection rate calculation on only those spelled words that are longer than the mean length of the spelled words that meet the criteria for consideration. For these subjects, that would bring the selection rate difference for the two sampling contexts to 17% and 4% respectively.

Likewise, communication rate can change from time to time and may be a function of the language sampling context. Since rate index is based on both selection rate and communication rate, these factors need to be considered in use of the rate index.

For people who are using similar AAC systems, rate index comparison can draw attention to opportunities for improvement in communication rate, even though the selection rates of the individuals may be vastly different. A relatively low rate index would prompt a closer review of the various other factors that contribute to communication rate: use of language representation methods, selection errors, spelling errors, etc. Comparison of these summary measures can be made without concern for selection rate differences.

Rate index can be a useful clinical tool in identifying opportunities to improve communication rate and hence communication effectiveness. The end result can be higher personal achievement for the individual who relies on AAC.

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# THE DEVELOPMENT OF AN AAC LANGUAGE SAMPLE LIBRARY TO SUPPORT EVIDENCE-BASED PRACTICE

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## ABSTRACT

Automated data logging for AAC (augmentative and alternative communication) is commercially available and in clinical use. A standard logfile format is used for language activity monitoring (LAM). The AAC field is developing an accumulation of performance data using LAM. This data constitutes evidence to support AAC clinical practice. In order to maximize the benefits of these developments, a web-based AAC language sample library has been established.

## BACKGROUND

AAC automated language activity monitoring (LAM) provides the field of AAC with tools needed to collect and analyze language samples both in the clinical setting and from natural environment communication. Hill and Romich (1) as well as Higginbotham and Lesher (2) have proposed standard protocols for automated data logging to address compatibility issues and facilitate the widespread application of actual user-performance data collection.

Language sample data can be edited and analyzed to provide information on language representation and text generation methods used, communication rate, various other language parameters, and non-language device function use. Research on user-performance using LAM tools has been documented for the school-aged population (3) and for persons with ALS (4). Implications of these tools are significant in the areas of clinical intervention, outcomes measurement, and research.

The goal of AAC is to provide the most effective communication possible for the individual being served. However, many clinicians and consumers do not have a vision of what is possible regarding being able to generate spontaneous, interactive communication using AAC systems. Researchers must gather all performance information for any research task. The impracticality and high cost of traditional language-sampling and observation methods historically restricted the monitoring of performance, especially within natural contexts and activities of daily living.

As acceptance of automated data logging and the standardization of logfiles has grown, the field of AAC has been generating an accumulation of performance data from a variety of sources and from a variety of augmented communicators. The research on the feasibility of the LAM has been supported by grants to Prentke Romich Company from the National Institute for Deafness and Other Communication Disorders of NIH. Work on a universal logfile format has been supported by the Rehabilitation Engineering Research Center on Communication Enhancement (the AAC-RERC), sponsored by the National Institute on Disability and Rehabilitation Research. For the first time, logged language samples are providing the opportunity to identify performance standards related to vocabulary size, vocabulary diversity, language representation methods, communication rate, and selection rate.

## STATEMENT OF THE PROBLEM

Speech-language pathologists (SLPs) providing services to people who rely on AAC need access to communication performance data for other successful individuals. This data can help to form the vision of what can be the expected result of the therapy process. However, data on communication performance of others is not generally available in a useful form. Access to a database of external evidence on AAC performance would address this need.

## METHOD

The objective of this study was to develop the software to support a website database of performance measures based on language samples recorded using automated data logging. Evidence-based clinical practice requires data. A language sample library (LSL) would provide practitioners, consumers, and others with evidence to support decisions that result in the most effective communication possible.

In order to facilitate widespread application of accumulated automated performance data from clinical, research and commercially available sources, an AAC database of language samples is being established on a web site at www.aacinstitute.org. The web-based AAC language sample library provides the field with a systematic and efficient database to support clinical intervention, outcomes measurement, and research activities. Web site solutions provide inexpensive access to precise and useful data not previously available to stakeholders (5). Similar databases are maintained for language samples of persons who use natural speech (6,7). The AAC language sample library allows for 1) readily available samples for clinicians to use for comparison purposes, 2) readily available samples for consumers to use for comparison purposes, 3) data to support the identification and measurement of AAC outcomes, and 4) data to support AAC research.

The language sample library web site follows a model consistent with previously established language transcript databases. Various web site features support ease of access and usability of the database. Additionally, instructional information is offered on LAM procedures and methods for handling raw LAM data. A proposed set of standard transcription entry conventions and codes to identify AAC performance are posted. Links to resources that support training on LAM and language transcription will be available as these educational tools are defined, developed, and evaluated.

To facilitate the retrieval of useful language samples, samples are organized by the profiles of the subject individual. For each profile in the library, one or more language samples exist. Profile categories include diagnosis, age, gender, cognitive ability, level of language functioning, physical access method, ethnic and regional background, native language, and sample collection method.

To retrieve a language sample from the library, one enters the user profile for which a sample is desired. Individual profile categories can be weighted differently for the matching process. The library returns a list of profiles ordered according to the best match with the entered profile. Upon selection of a profile, a chronological list of the language samples for that profile is presented. Standard sampling methods under research include picture description, interviews, and conversations. In addition, the database sorts samples according to language representation methods used, AAC hardware, and AAC software. Since the goal is to promote the most effective communication possible, profiles with the highest performance are given highest retrieval priority.

## DISCUSSION

Implications of the language sample library, like those of the concept of language activity monitoring, fall into three areas: clinical intervention, outcomes measurement, and research.

*Clinical Intervention:* The language sample library allows clinicians to compare the language samples of individual clients with the samples of augmented communicators maintained in the library. In addition, consumers can access the database to make comparisons and informed decisions about their communication performance.

*Outcomes Measurement:* With the current interest in accountability of AAC supports and services, improving databases as well as integrating them across service delivery sectors and geographic borders can have a tremendous impact on outcomes measurement (8). Quantitative data from augmented communicators are needed to substantiate the effectiveness of AAC models, technology, and intervention strategies.

*Research:* A database of language samples provides comparable, compatible, and reliable quantitative data for a variety of research applications. A common share pool of samples guarantees that the results can easily be compared across samples for criteria, and provide the opportunity to investigate issues of reliability and validity that may be associated with various summary measures.

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# A MODEL FOR AAC EVIDENCE-BASED CLINICAL PRACTICE

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## ABSTRACT

Augmentative and alternative communication (AAC) evidence-based clinical practice is the approach to AAC service delivery generally considered to result in the most effective communication. Evidence-based practice requires data collection and outcomes measurement. It also requires of knowledge of evidence of communication performance that may be expected of the subject individual. Methods, tools, and evidence are available to support practice. A model for using these resources is presented.

## BACKGROUND

AAC service delivery has been making a rapid shift from the art form of the past to the science of today. By virtue of the important language component, AAC service delivery is the domain of the speech-language pathologist (SLP), often working on a team with other professionals and stakeholders. The American Speech-Language-Hearing Association (ASHA) has recognized the shift toward scientific methods through the revised ASHA Scope of Practice, the very definition of the profession of speech-language pathology in the United States (1). That document now articulates the expectation of data collection, outcomes measurement, and provision of services in accordance with the principles of evidence-based practice.

Evidence-based practice means integrating individual clinical expertise with the best available external clinical evidence (2). Historically at the case level, the best available external clinical evidence has been collected using traditional or manual methods of observation and analysis. Currently, automated performance monitoring is providing methods and tools that report quantitative data based on units of measurement to support clinical decisions. External clinical evidence replaces previously accepted treatments with new ones that are more powerful, more accurate, and more efficacious (2).

A language activity monitor (LAM) was developed originally as a device to be added to existing AAC assistive technology systems (3). Several modern high performance AAC systems now have the data logging function as a built-in standard feature. Methods have been developed to use the LAM data to generate a summary measure report of communication performance (4). Software applications such as the Augmentative Communication Quantitative Analysis (ACQUA) (5) and others are forthcoming for automating the analysis process. Clinical research has reported evidence on summary measures that includes number of utterances, percent complete, percent spontaneous, mean length of utterance, total number of words, number of word roots, average and peak communication rates, selection rate, rate index, use of and communication rate using difference language representation methods, selection errors, and spelling errors. Progressive AAC practitioners are using these methods and tools to accumulate data. The students of progressive university SLP programs are learning to use them prior to their first clinical experience.

## STATEMENT OF THE PROBLEM

Without evidence-based practice, achieving the most effective communication possible for the individual cannot be expected. While the notion of evidence-based practice is accepted and the methods and tools are available, many practicing SLPs have not received formal training on how to take this approach. Many university SLP training programs still do not offer a course on AAC, although over two thirds of SLPs claim to include AAC in their practice (6). Many AAC courses only have time and resources to teach the basics, leaving students without course content on performance evidence. The literature on evidence-based medicine frequently references levels of evidence, but does not depict the steps associated with clinical data collection, especially AAC assessment and intervention.

## APPROACH

An AAC evidence-based practice flow chart (Figure 1) has been developed to serve as a systems model for clinical service delivery. The model reflects use of the recently developed methods and tools and the growing body of evidence of communication performance that can be achieved by various populations of individuals who rely on AAC.

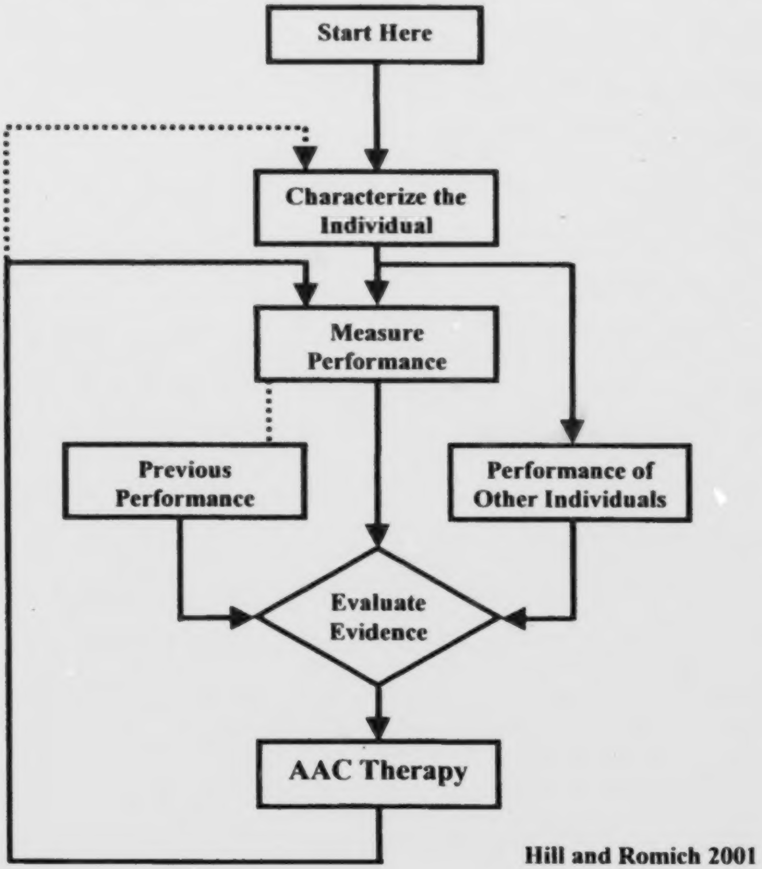
Start Here
Characterize the Individual
Measure Performance
Previous Performance
Performance of Other Individuals
Evaluate Evidence
AAC Therapy
Hill and Romich 2001

Figure 1: A model for AAC evidence-based clinical practice.

The process starts with characterizing the individual. The primary purpose of this step is to permit the retrieval of the communication performance that others with similar profiles have been able to achieve. Then the communication performance of the subject individual is measured. This can be done using automated language activity monitor to collect a language sample and then analyzing the LAM data to create a performance report. The performance is compared to that of others and also to the previous performance of the individual. The results of both of these comparisons drive the therapy process. Response to therapy is determined by reiteration of this process starting with performance measurement. When the individual's characterization changes, such as with aging, diagnosis, education, etc., that should be noted with corresponding changes to the Performance of Others. Documentation of progress and outcomes measurement is inherent.

## DISCUSSION

As in good medicine, good AAC practitioners use both individual clinical expertise and the best available external evidence to support practices. This model blends clinical expertise with data to provide the services that result in the most effective communication for individuals who rely on AAC systems. Depending on other factors, the frequency of use of the model may range from weekly with every therapy session to quarterly. A growing library of analyzed language samples (7) can be accessed for the Performance of Others. Practical use of this model should automatically satisfy the IDEA (Individuals with Disabilities Education Act) requirements of outcomes measurement for every student on an IEP (Individualized Education Plan). Inclusion of this model and related performance reports can substantially strengthen requests for funding for AAC assistive technology.

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# LEVERAGING WORD PREDICTION TO IMPROVE CHARACTER PREDICTION IN A SCANNING CONFIGURATION

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## ABSTRACT

A considerable switch savings can be realized by adding a linearly scanned character prediction list to a static matrix scanned in row-column fashion. Past studies of such systems have utilized simple ngram and kgram character prediction methods that utilize only the current word context to generate the character list. Advanced word prediction algorithms can take advantage of several words of past context to predict likely words. This technology can be leveraged to improve the accuracy of character prediction, and thereby provide greater switch savings to a scanning system. Averaging switch savings during the production of seven representative texts, we found that adding word-based character prediction to a conventional character prediction approach can improve performance from 22.6% to 30.4%.

## BACKGROUND

Although a substantial body of research has been devoted to improving word prediction methods in AAC, there have been few investigations into more effective character prediction techniques, despite the important role that accurate estimation of letter probabilities can play in augmenting communication. Our research has indicated that character prediction can provide better switch savings than can word prediction in certain scanning paradigms – over 30% in some cases (Lesher, Moulton, & Higginbotham, 1998). Other areas critically-dependent upon accurate character prediction include disambiguation for ambiguous keypads, spelling correction, and automatic abbreviation expansion.

Two common types of character prediction are generally utilized in AAC (Baletsa, Foulds, & Crochetiere, 1976). Both types rely upon a database of inter-character statistics, generated by analyzing a large corpus of representative text. In ***ngram*** prediction, the past $n$-1 character are used to predict the current ($n^{th}$) character. In ***kgram*** prediction, the first $k$-1 characters of the current word are used to predict the current ($k^{th}$) character. In general, kgram character prediction is more accurate. However, because kgram prediction breaks down when the user is typing words that didn't occur in the source corpus, ngram predictions are often used as a safety fall-back.

Character prediction generally relies only upon characters in the current word – although it's possible to use ngram techniques across word boundaries, they are generally not very effective. Word prediction, on the other hand, can be designed to take advantage of several words of past context. Our research team has performed extensive research into advanced ngram word prediction techniques, discovering prediction models that can provide keystroke savings of nearly 60% in a direct selection paradigm with a six word prediction list (Lesher, 1998).

Any word prediction method can be leveraged to generate character distributions by tabulating the probabilities of each character across each predicted word. For example, if after typing "th" the predicted words and associated probabilities were (the:0.5, there:0.2, this:0.2, though:0.1), the predicted characters would be (e:0.7=0.5+0.2, i:0.2, o:0.1). Provided that the word prediction technique is more accurate than kgram word completion, this approach will provide more accurate probability estimates than can kgram or ngram character prediction. A preliminary study using an ad hoc trigram ($n$=3) word prediction model to produce the character prediction list in a scanning system yielded an average switch savings of 2.4 percentage points (Lesher et al., 1998). Our research team felt that greater savings could be realized in a more thorough investigation of word-based character prediction.

## RESEARCH QUESTION

The objective of this investigation was to establish how effectively advanced ngram word prediction algorithms could be utilized to increase the performance of a scanning array supplemented by a character prediction list. More specifically, we were interested in defining a method for combining word predictions with character predictions such that the resulting character list would minimize the switches necessary to generate a given message.

## METHOD

Given a list of predicted words with associated probabilities, generating a character prediction list is straight-forward – one simply sums up the probabilities of each character for the current character position, then ranks the characters by summed probabilities. Of course, the length of the word prediction list will determine the accuracy of the character predictions. If the list only contains a few words, the resulting character probabilities will be skewed by the insufficiently large sample set. It is therefore important to use a longer prediction list than would typically be used with a word prediction interface. We found that a 50 word list was usually sufficient to ensure the accuracy of word-based character prediction. It is also possible within our evaluation software to set up a "virtual" word list that has no length limit. The computational requirements of this method are very substantial, and the accuracy gains minimal, so our studies utilized finite-length lists.

Our studies used a scanning model with supplemental character list, as described in Lesher et al. (1998). In this paradigm, a prediction list of 5 characters was scanned in a linear fashion before a static character matrix was scanned in a row-column fashion. The matrix was optimized for character prediction, such that characters that are not generally predicted well appeared in the upper left corner of the matrix (where they were easier to select). Our IMPACT evaluation platform was used to autonomously reproduce seven representative testing texts with lengths between 5 and 10 thousand words, keeping track of the required number of switch activations for each. Baseline switch counts were generated using a static matrix optimized for row-column scanning (the "Time logical" arrangement from Lesher et al., 1998). Switch savings were then calculated and averaged over the seven texts.

## RESULTS

Word-based character prediction provided much more substantial performance improvement than we had anticipated, increasing switch savings by nearly 8 percentage points, from a baseline of 22.6% to 30.4%. This gain was consistent across each of the 7 testing texts. In our past studies of character and word prediction techniques (Lesher, 1998; Lesher et al., 1998), we have never witnessed a larger jump in performance that could be attributed to the addition of a single new algorithm.

While our pilot studies produced results that provided less than 3 percentage points, we found that increasing the relative weight of the word-based character prediction engine (with respect to the traditional kgram and ngram prediction components) provided substantial gains. Performance plateaued when the weight of the word-based component reached approximately 50%, and started to fall off again once the weight exceeded 90%.

## DISCUSSION

The impressive gains realized by supplementing traditional character prediction techniques with context-sensitive word prediction methods have the potential to substantially increase the communication rate of persons forced to use scanning selection. Assuming constant switch selection times, an 8 percentage point switch savings theoretically translates to a rate gain of slightly over 11% (given by: (30.4-22.6)/(100-30.4)). By reducing the number of switch activations necessary to generate a given message, these prediction methods also help to minimize fatigue.

Despite the significant savings in switch activations offered by conventional ngram/kgram character prediction methods, there have been no comprehensive studies of these methods on communication rate. Indeed, only one commercial system (Enkidu Research's Portable IMPACT) even offers character prediction as a scanning option. The attentional requirements of monitoring a constantly changing character list will likely necessitate a decrease in scanning rates, which may offset some or all of the switch savings. The additional effects of the word-based prediction techniques described in this paper on the cognitive and attentional loads of character prediction are unknown. However, given the large savings in switch activations, it seems likely that these techniques will yield net improvements in communication rate when compared to conventional character prediction methods.

A number of supplemental techniques for improving character prediction performance were investigated by Lesher et al. (1998). These include delaying character prediction until after the first letter in each word is entered and additional optimization of the static character matrix. In the future, we will investigate how word-based character prediction methods can be integrated with these methods to further improve system performance. In addition, we hope to apply these techniques to the disambiguation of ambiguous keypads such as those found on telephones.

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# EFFECTIVE PARTICIPATION OF PERSONS USING AAC IN A MIXED GROUP OF USERS AND NON-USERS OF AAC

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## ABSTRACT

This paper describes approaches for collecting data from AAC users to ensure their full participation as experts in discussions between users and non-users of AAC. The study responded to the logistical challenges of involving AAC users in an inclusive Stakeholder Forum designed to identify the highest priority needs of the AAC Industry.

## BACKGROUND

The goal of the Demand-Pull project of the T$^2$RERC is to transfer technologies that overcome the highest priority limitations of products in the Assistive Technology marketplace. Stakeholder involvement, in particular full inclusion of end-users, is an essential component of the project. The Stakeholder Forum is a significant event where expert groups of technology producers, manufacturers, researchers and end-users discuss unmet customer needs. The Forum occurs over a two-day period where four groups of 15-20 stakeholders explore each of the selected technology areas. These technology areas represent limitations in the functions of existing products. At the Forum, moderators enable the attending experts to reach a consensus of technology needs and to establish requirements for technology solutions to address these needs [1].

In year three, the project focused on the Alternative and Augmentative Communication (AAC) industry. The T$^2$RERC's challenge was to maintain the Stakeholder Forum's principle of full inclusion of end-users to obtain their perspectives on the needs and limitations of current technologies. AAC represents additional issues for inclusion in real-time discussion that all center around the temporal demands of interaction (i.e. composing statements on the spot). Examples are: The communication inefficiencies and message-timing limitations are said to interfere with the communication interactions of many AAC users who use symbols to communicate. Users of direct selection systems can average 13 to 43 words per minute when communicating [2], significant when compared to speaking rates for non-disabled individuals (126-200 words per minute) [3]. "Many non-AAC using partners…appear to be uncomfortable with the latency of communication and length of time necessary for many AAC users to formulate messages" [4].

We needed to resolve whether there existed a trade-off between real-time participation and quality responses from consumers. In other words, to what degree face-to-face (FTF) assured full participation without detriment to the quality of data obtained by AAC users? To address this issue we considered two options. First, comparing the FTF method with Computer-Mediated-Communication (CMC), an alternative strategy for collecting input from a group of users of AAC [5]. In CMC, the computer mediates the communication process between the people involved and facilitates the transfer of information and preservation of information. CMC eliminates the temporal concern because it allows people to participate in an asynchronous fashion from remote locations. Further, it permits participants to fully develop their thoughts in text form, which is assumed to result in richer responses. Despite these advantages, applying CMC would violate the T$^2$RERC's principle of full participation of end-users synchronously with all other Stakeholders at the Forum.

Second, we explored a feasible method of maintaining face-to-face (FTF) participation with modification, including supplementing a script of questions distributed prior to the Forum. One concern was that the real-time participation would lose the benefits of CMC, where participants are able to explain and expand upon their results without being constrained by time.

To answer these uncertainties, we conducted a preliminary study comparing the processes and products of including end-users in the consumer panels by using the CMC and FTF methods.

**OBJECTIVE**: (1) To determine how FTF method compares with CMC in terms of data yield and (2) to contrive a feasible strategy of including AAC users in mixed groups, using the effective method, based on the study observations.

## METHOD

The CMC method was used for one group of about 25 participants and the FTF method was used for a second group of 15 participants, divided into two sessions. Sampling was purposive, with focus on information-rich cases (expert consumers) that would give valid coverage to all AAC technology. Participants were richly experienced, high-end technology users. The average age was 35.85 years (s.d.=12.67). The amount of time using AAC averaged 20.80 years (s.d.=10.77). The most commonly used devices were the Liberator (52%), Dynavox (17%) and LightWriter (11%). Regarding educational level, 26% were postgraduates, 49% were college graduates and 20% had attended high school only. The discussion involved 10 questions including: "What are the environments, situations or activities in which the AAC device is not useful or effective?" and "Identify the features that you would most like your AAC device to have." The survey also included an evaluation (strengths, weaknesses, needed improvements and barriers) of a number of features and functions of AAC technology.

## RESULTS

After the panel study, we compared the results of the two processes and determined that for our purposes, they provided essentially identical information. CMC provided richer, but not necessarily more relevant data in terms of input for the Forum. While CMC data ran to a length of 65 pages, the FTF gave us the essential data in 15 pages. However, the CMC process took longer and clearly did not substitute for the real-time exchange and convergence we encourage. The CMC process took eight weeks in all whereas each FTF session consumed 3.5 hours. We decided to conduct the Stakeholder Forum in a face-to-face format with full inclusion of AAC users.

The Forum was held in Buffalo, NY in June of 2001 and consisted of four moderated groups of 15-20 people consisting of users and non-users of AAC. Seventeen percent (17%) of the 70 participants were users of AAC technology. Because AAC users found advance materials helpful in preparing for the face-to-face panel, we provided a general script of the discussion questions prior to the Forum. This gave participants the option to prepare their responses beforehand and be more able to readily participate in the dialogue as it evolved. We further ensured their full engagement in the discussions, by moderating the sequence of participant responses so as to prioritize and maximize the opportunity for end user responses. Due to the time constraints, we also asked users to prepare their responses quietly while others spoke. The Forum's real-time discussion allowed each participant to react to the issues, concerns and needs of each other. The discussions converged on technology needs that led to a list of Problem Statements, as occurred in prior Forums.

Results were further validated at the Forum by an evaluation survey regarding full-participation which all participants completed (i.e. I was given enough time to respond to questions, I felt comfortable participating, The aspects that were most helpful in allowing me to fully participate were and I made useful and relevant contributions to the discussion). Participants using AAC manifested high satisfaction in the Forum, as noted in the post-Forum responses to this survey. Many stated that they enjoyed the patience shown by the group, and liked seeing others participating who had similar strengths and weaknesses. One participant felt that answering the questions beforehand was the most helpful in allowing her to fully participate. Another commented, "I got a chance to meet other stakeholders. I am very happy that end-users are involved, and it needs to continue that way".

Other stakeholders also commended us on the high level of participation, only stating that even more consumers be included. General comments included "the fact that everyone, almost without exception, actively participated was helpful." The opportunity to interact with AAC users was a particularly valued benefit. Ten out of 45 volunteered comments such as, "the multi-disciplinary participation, including especially the consumer" gave way for "multiple viewpoints and interactions that aren't normally possible." Despite the concerns, the $T^2$RERC was able to obtain consumer information that validly described the highest priority needs of the AAC industry.

## DISCUSSION

The principle of full inclusion and full participation is critical. The holding of a Forum in a face-to-face format is of utmost importance for participants to react to the multiple perspectives of others and to arrive at consensus regarding technology needs. In years one and two, the Wheeled Mobility and Hearing Enhancement projects were successfully conducted with full end-user inclusion. The apparent challenge of including the AAC user this year was also overcome. This study has shown that there are ways to overcome the barriers and have full inclusion of AAC users regardless of their disability. With modification, we were able to achieve full AAC user participation, maintain our face-to-face protocols at the Forum, and write the Problem Statements.

A full report on the Problem Statements was disseminated in January of 2002 throughout mainstream industries, universities and other research facilities, and the Federal Laboratory Consortium in order to obtain viable solutions to fill the gaps jointly identified by the participants. These technology solutions can then be transferred to the AAC industry. For an electronic copy of the Problem Statements, please visit our website's link to the Demand-Pull Project on Communication Enhancement http://cosmos.buffalo.edu/aac.

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# CONNECTING AAC DEVICE VIA MOBILE HANDSET TO THE OUTSIDE WORLD

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## ABSTRACT

Mobile telephone technology has come into common use in our society, both for voice communication and for information access. For people with disabilities, the function of mobile telephones can extend well beyond the convenience that most users enjoy. It can mean a level of independence not otherwise possible. Some people who rely on AAC (augmentative and alternative communication) are among those who do not have the physical ability to use a standard mobile telephone. For this population methods of operating a mobile telephone from an AAC system for both speech and data communication are available.

## BACKGROUND

People who rely on AAC have identified access to mobile telephone technology as an area of need (1). While some have the physical ability to press the buttons on a conventional mobile speakerphone, others do not. Further, many have the desire to achieve Internet access through their AAC assistive technology. If this is being done by anyone, it most certainly is uncommon. One of the goals of this project was to demonstrate the potential solutions available for satisfying this need.

## STATEMENT OF THE PROBLEM

The numerous companies, organizations, and individuals that address populations with special needs require information on mobile phone connection that is usually not available to them. These needs often relate to the connection of other products to relay speech communication and/or data. Accessibility to mobile phones has had some previous attention (2). This paper is trying to shed additional light into this problem by starting with a brief introduction to controlling a Nokia mobile handset via AT commands. Whether this method is available with a handset is dependent on the model and version of the handset and the network infrastructure. Then a study is presented where a mobile handset is enabling an AAC device to make cellular phone calls and to connect to the outside world.

## DESIGN

The configuration of the AAC system / mobile phone connection required no customization with the exception of the modification to the earphone / microphone assembly.

### AT command set

Computers use AT commands to control modems (3). Nokia mobile phones with internal modems can also be controlled via a restricted AT command set. This is an industry standard protocol and is compatible with mobile phones and computers of essentially all manufacturers.

The restricted AT command set available in the mobile phone enables the user to initiate, dial, and end phone calls via an external device. It is not, however, possible to modify the user interface or functionality of the phone in any way. Every AT command starts with letters AT:

To initiate a call: ATD2145555214;, where D is for dialing and 2145555214
is the phone number, and ";" designates voice connection.

110

To hang-up: ATH0, where H is for hook and 0 frees the connection.
To answer an incoming call: ATH1, where 1 makes the connection.

**Connection to the mobile handset**

The actual connection between the phone and the other device has three existing choices depending on the model of the Nokia mobile handset: serial, infrared (IR) and Bluetooth (3). As with the AT command set, all three of these media conform to industry standards. The serial connection is an RS-232c connection using a cable between the two devices. The IR connection in Nokia handsets is compatible with the IrDA standard and it doesn't require a cable, but requires a line-of-sight in order to function properly. The infrared link is activated via phone menus and once activated it stays on as long as the communication is active. The Bluetooth connectivity is utilizing radio frequency (RF) link on 2.45GHz ISM band (2). Therefore it doesn't require cables nor line-of-sight. When two Bluetooth compatible devices come within 10 meters of each other, they can establish a connection. Devices that have Bluetooth capabilities can actually set up a network together due to point-to-multipoint connection possibilities. Nokia Bluetooth connectivity packet for the phone requires a phone with Bluetooth capabilities (Bluetooth battery) and a Bluetooth module for the other device. The Bluetooth module is inserted into a PCMCIA slot in the system.

**Connecting an AAC device to the outside world via mobile handset**

The AAC device in thisstudy was a Pathfinder manufactured by Prentke Romich Company. The Pathfinder is a speech output communication device for people with speech impairments. The user interface of the Pathfinder consists of a static keyboard and a touch screen. The Pathfinder supports all three language representation methods: single meaning pictures, alphabet-based methods, and semantic compaction. The Pathfinder output is synthetic and/or digitized speech. The device also has an IrDa infrared connection and a serial port as well as a PCMCIA card slot that could be used with a Bluetooth module. Thus, the Pathfinder is an ideal system on which to test various interface configurations.

The purpose of the study was to demonstrate speech communication via mobile handset through an AAC system. This would enable the person who relies on AAC to interact with friends and relatives as well as use phone accessible services at will anytime and anywhere. The prototype system utilizing a Nokia handset and Pathfinder is depicted in Figure 1 and it was done as a co-operation between Nokia and Prentke Romich Company.

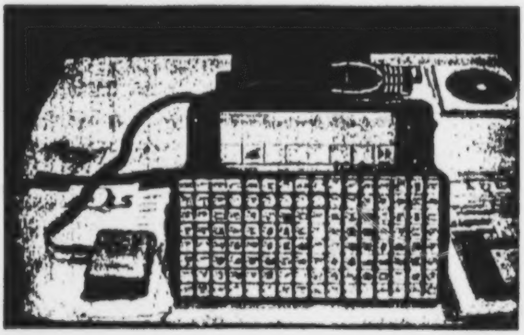

Figure 1: Nokia mobile telephone connected to Pathfinder AAC system.

**EVALUATION**

The assembled system was tested by making calls. AT commands were stored in the Pathfinder under icon sequences. One sequence was for OFF HOOK and one for ON HOOK. Commonly dialed numbers were stored under icon sequences that represented the called party.

The system in this study is utilizing

AT commands via infrared connection to dial, initialize and end the phone call. The phone numbers are programmed into the Pathfinder and they are accessible via the icon-based interface. The infrared (IR) link in the phone has to be activated by hand when the phone is turned on. But once the IR link is active it stays on as long as Pathfinder continues data transmission with it. In this application Pathfinder keeps polling the mobile phone continuously even between the phone calls to maintain the IR link with the handset.

The audio link between Pathfinder and the mobile phone is established via a modified phone headset. The headset is split into two parts in such a manner that the microphone in the headset is mounted near the speaker of the Pathfinder and the earphone of the headset is replaced by an amplified speaker that allows the user to receive audio without using a headset. The result is similar in function to a speakerphone. Of course the option of using a headset is always available.

## DISCUSSION

This small study demonstrates that sometimes breaking the barrier to the wireless world requires a rather small effort compared to the results that can be achieved. Not only in the field of disabilities but also in many other areas such as well being, medical, and security, just to name a few.

The battery charge life in the system described as a study in this paper is reduced due to the continuous IR connection. This issue could be eliminated through various means of using the wheelchair battery to charge the phone battery as is done in automotive applications. The other way to deal with the energy problem would be software modifications that would allow the IR link to be established only when necessary via the touch interface. In the present version the IR link in the phone has to be activated most likely by another person since the user is not likely to be able to use the phone due to disabilities. A serial cable connection is expected to reduce power consumption but was not tested.

The connection of a mobile phone into an AAC device such as Pathfinder opens up more ways for a disabled person to interact with the surrounding world. Pathfinder and some other dedicated AAC systems are built on the WindowsCE paltform. This means that they have the potential for Internet access, fax transmission, and other messaging which could be mobile through such a connection. Using the Bluetooth technology would bring another short-range connectivity method parallel to IR and serial connection.

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# Computer Access and Use
# (Topic 3)

# WEB PAGE USABILITY TESTS FOR BLIND USERS OF TEXT TO SPEECH SYSTEMS

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## Abstract

User-tests that are relevant for assessing usability of web pages to visually impaired users of text to speech programs are presented here. They have been justified with reference to the Web Content Guidelines 1.0. Their relevance and comprehensiveness has also been gauged from the responses obtained from other screen reader users and web accessibility proponents.

## Background

People with disabilities very often need to use a piece of assistive technology (hardware or software) to gain access to a computer and the Internet [1]. Usability of a web page for a person with a disability is therefore a function of the accessibility features incorporated into website design and the ability of the assistive technology to interact with the web page. Therefore, in the context of people with disabilities using assistive technology for web access, usability of a website can be perceived only with reference to its usage context that includes the individual and the assistive technology. As usability of any item can be defined with reference to a particular context, its measure too should be in the same context [2].

Software tools exist that can efficiently check HTML code underlying web pages for compliance with objective criteria governing their development so that they are accessible to people with disabilities. The Web Access Initiative's (WAI) Web Content Guidelines acknowledge that, "Human review can help ensure clarity of language and ease of navigation". It further suggests that better usability levels can be attained through web page reviews by people with disabilities using assistive technologies [3]. The guidelines classify the checkpoints into three priorities based on their significance to accessibility that certainly aids developers to channel their efforts to ensure that critical accessibility issues are addressed. But it is not necessary that usability measures are solely based on these checkpoints and regard the prioritization as sacrosanct.

Visually impaired individuals are the most challenged of web surfers and a significant number depend on add-on software programs that convert screen text to synthesized speech [4]. A recent qualitative study that focused on identifying web page design features which impede efficient web usage by persons with visual impairment observed that with current Web design practices, users without disabilities experience three times higher usability than users who are blind and use screen readers [5]. People with disabilities using assistive technology to access the Internet are well placed to assess website usability [5]. However, a vacuum exists in specifying the user-tests that need to be carried out to assess the usability of web pages with any given class of assistive technology like screen readers or screen magnifiers.

## Statement of The Problem

To develop a valid set of specific user-tests that can mainly be performed by a visually impaired user of a text to speech program to assess usability of a web page.

## Rationale

Like any Internet surfer a blind user too is mainly interested in being able to identify what is presented on a web page, access the portion of interest and the information content, use online forms to request specific information or services or products and use keyboard equivalent commands rather than the mouse to interact with the web page. The Web Content Guidelines 1.0 and Electronic And Information Technology Accessibility Standards issued under Section 508 of the reauthorized Rehabilitation Act, 1998 also contain specific checkpoints or standards for making the above-referred tasks accessible to people with disabilities including blind users of text to speech based assistive technology.

It is important to define specific user-tests that address these concerns and as a first step, obtain the concurrence of other blind users of text to speech software as well as web access specialists that the tests are relevant and comprehensive.

## Design and Development

The researcher has identified a list of twenty-four user tests based on his experience of surfing the web using text to speech software. These have been grouped under five heads:

A. Navigation Tests: Five user tests assess manner of naming links, their organization and presentation [1], [6].
B. Tests For Layout and Access to Information: Eight user tests assess adequacy of text descriptors for graphics, use of tables and headings on the web page and alternative style of presentation for .pdf files [1], [6].
C. Forms Tests: Seven user tests assess usability of online forms [1], [6].
D. Comfort level assessment: This is a subjective measure of the frustration or comfort experienced by the user.
E. Tests with Sighted Assistance: Three user tests complement the above and assess whether graphics are adequately described and scrolling/blinking text or use of colors do not present accessibility problems to the blind user [1], [6].

Each test is assigned a lower or higher weight (1 or 2) to signify its relative importance in the usability measure. Half the tests affect success/failure of task completion or level of access to content and have a higher weight of 2. The remaining tests affect efficiency and have a lower weight of 1.

Not all tests are applicable to every web page. For instance if a web page has no table, then user tests concerning their accessibility do not apply; similarly, if a web page has no form, the associated tests are not applicable. Thus the maximum score possible or the denominator value varies for every web page. Responses along an ordinal scale are provided for all tests. Besides a "Not Applicable" (NA) reply, every test has either two or three possible responses and a desirable answer has a higher score associated with it. A valid score on every test is expressed as a percentage of the maximum score possible for that test. The usability score for a web page is then calculated as the simple mean of percentage scores on all applicable tests duly adjusted for their respective weights.

## Evaluation

1. Every test has a justification for its inclusion with reference to a specific guideline and/or checkpoint contained in the Web Content Accessibility Guidelines 1.0 as well as the checkpoints listed under Section 1194.22 of the Electronic And Information Technology Accessibility Standards issued under Section 508 of the reauthorized Rehabilitation Act, 1998. The specific guideline/checkpoint is also stated after every test. This is done to establish the validity of the testing framework.
2. The list of user-tests was sent out to experts in the field of web accessibility and users of screen readers to elicit feedback and determine face validity, including relevance and

comprehensiveness of the tests. Table 1 shows response rates for three categories of reviewers.

Table 1: Three categories of respondents who reviewed tests

| Category | Number Contacted | Number Responded |
|---|---|---|
| Visually impaired users of screen readers | 13 | 7 |
| Web accessibility practitioners/consultants | 3 | 3 |
| List serve of visually impaired computer users | 1 | 0 |

## Discussion

It is not only how effectively a web page adheres to established guidelines for accessibility but the manner in which an assistive technology like a screen reader handles a web page element that affects the final usability measure. It is indeed necessary to examine the experiences of assessing usability of web pages based on these tests by a set of visually impaired individuals using different software programs in order to establish the validity and reliability of the user tests. However, to begin with, one needs to identify a set of user tests that appear to be comprehensive and fairly valid and this is what has been accomplished at this stage. Although opinions of reviewers do enforce credibility of the tests, it will be useful to check if the usability measure can be related to accessibility measure in terms of error-count identified by a tool like Bobby V 3.2. This analysis is now being undertaken.

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# W3C User Agent Accessibility Guidelines

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## Abstract

The W3C User Agent Accessibility Guidelines (UAAG) is part of the W3C Web Accessibility Imitative. UAAG is designed to provide information on how user agents (browsers and multi-media players) can be design to be more accessible to people with disabilities and compatible with assistive technologies. UAAG is developed through the consensus-based process of the W3C, which includes participation from user agent developers, disability researchers, service providers, disability organizations, and people with disabilities.

## Introduction

The W3C User Agent Accessibility Guidelines (UAAG) (1) are part of the three major guidelines that have been developed by the W3C Web Accessibility Initiative (2). The other two guidelines include the Web Content Accessibility Guidelines (3) and the Authoring Tools Accessibility Guidelines (4). The User Agent group has the responsibility to develop a set of guidelines that help developers of web browsers and multi-media players to design their technologies to be more directly accessible to people with disabilities and compatible with assistive technologies. The document is now in the Candidate Recommendation (CR) stage of the W3C Process (5). During CR the working group is working with developers to implement the requirements of the guidelines and document known implementations of the requirements. It is anticipated the document will move to the Recommendation stage of the process during the Spring of 2002. The working group includes participation of developers of mainstream user agent technologies, assistive technology developers, people with disabilities, disability researchers and experts in the use of assistive technologies.

In addition to the guidelines document the group has produced a Techniques Document (6) that gives implementation ideas to developers on possible ways to satisfy the requirements of UAAG. The techniques document is organized to provide direct links between UAAG requirements and the relevant techniques. Techniques are gathered through reports on actual implementations and ides from working group members on possible implementations.

The group is also producing an Implementation Report (7) to document existing implementations of each requirement. The implementation report is important to help developers see that all the requirements are readily achievable within existing technologies and to help consumers see what types of accessibility features they can expect and request from developers of web technologies.

UAAG has requirements to address both built-in accessibility features and compatibility with assistive technologies. An important assistive technology compatibility requirement is the use of the W3C DOM (8) for communication of web content (HTML and XML) to assistive technologies. This gives assistive technologies direct access to the HTML and other XML based resources used to render the web document. This will allow assistive technologies to create more usable interfaces to web technologies by allowing them to directly access the original content of the resource author.

The working group is also a preparing a document (9) which compares the UAAG requirements with the Section 508 requirements (10). The documents share a lot of the same requirements, although UAAG has a number of requirements which are not a part of Section 508. An understanding of the similarities and the differences between the two documents will help developers plan their implementation strategies for improving disability access.

### Major Principles of Guidelines

There are 12 major guidelines included in UAAG. Each of the 12 guidelines is designed to provide developers with a general concept that is important for accessibility. Each guideline has a set of checkpoints that provide specific requirements for accessibility. Each checkpoint has an associated priority. The priority is an indication of how important a particular requirement is for accessibility. Priority 1 checkpoints are considered critical for accessibility and not implementing these requirements will make it impossible for some types of disabilities to use the user agent. Not implementing priority 2 checkpoints will make it difficult for people with some types of disabilities to use the user agent. Implementing priority 3 checkpoints will make it easier for people with disabilities to use the user agent. Currently there are 48 priority 1 checkpoints, 33 priority 2 checkpoints and 9 priority 3 checkpoints.

### List of UAAG Guidelines

1. Support input and output device-independence
2. Ensure user access to all content:
3. Allow configuration not to render some content that may reduce accessibility.
4. Ensure user control of rendering.
5. Ensure user control of user interface behavior.
6. Implement interoperable application programming interfaces.
7. Observe operating environment conventions.
8. Implement specifications that benefit accessibility.
9. Provide navigation mechanisms.
10. Orient the user.
11. Allow configuration and customization.
12. Provide accessible user agent documentation and help.

### Conforming to the Guidelines

The conformance section of the guidelines was one of the most difficult areas of the document for the working group to resolve. There are three levels of conformance a developer can claim to the guidelines: single A, double A and triple A. These are the same levels as defined for the WAI web content (3) and authoring tools guidelines (4). The single, double and triple A levels of conformance correspond to satisfying all the priority 1, priority 2 and priority 3 level checkpoints.

The conformance has an applicability clause. Some of the checkpoints deal with technologies or features that a particular user agent does not support. In this case the developer making a conformance claim must document which of checkpoints they felt did not apply to their product. To assist developers and consumers in simplifying these claims the working group choose to create predetermined sub groups of checkpoints for particular media types like text, graphical, video, audio and speech. In this case developers can use a label instead of specific checkpoints to indicate the groups of checkpoints that apply to their product. The labels will make it easier for consumers to understand what types of media the user agent is claiming conformance for accessibility.

## More Information

The user agent working groups activities are all public. The current working drafts of the guidelines and techniques documents, minutes from meetings, working group participant information and the e-mail list archives can all be accessed through the working group's home page at http://www.w3.org/wai/ua

## Acknowledgments

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# MOUSE EMULATION USING THE WHEELCHAIR JOYSTICK: PRELIMINARY PERFORMANCE COMPARISON USING FOUR MODES OF CONTROL

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## ABSTRACT

A Joystick to Mouse Adapter (JMA) has been designed which allows a power wheelchair joystick to provide proportional control of a computer or augmentative and alternative communication (AAC) system cursor. This provides people with the ability to use a single input method for both the wheelchair and the computer or AAC system. The JMA has three modes: proportional pointing, proportional directed scanning, and a hybrid of the two. Performance with able-bodied was measured using these three modes plus the traditional method of converting the wheelchair joystick signal into four switches.

## BACKGROUND

Many people who use power wheelchairs also require access to computers and other assistive technologies, such as augmentative and alternative communication (AAC) devices and electronic aids to daily living (EADLs). Often, each device has a separate input method. However, a person may have a limited ability to physically operate these devices, and may only be able to achieve reliable and effective control at a single site (1). In this situation, the person may attempt to control multiple input devices mounted at the same site, or may rely on a caregiver to switch input devices when the person wishes to change tasks. A third alternative is to use an integrated control system. An integrated control system allows a person to operate several pieces of assistive equipment through a single, universal input device (2).

The development of a mouse emulator based on the powered wheelchair proportional joystick was reported at RESNA 2001 (3). The hypothesis behind this design effort was that proportional control would provide a higher level of performance than the traditional approach of converting the joystick position into four switches that then are translated into mouse emulation. This paper presents results of a preliminary performance comparison study.

## RESEARCH QUESTION

The hypothesis driving this study is that proportional pointing and directed scanning result in higher performance than switch-based directed scanning. The objective was to evaluate the performance of four modes of control of a computer cursor using a powered wheelchair joystick. The personal achievement of many people with disabilities is related to their ability to create and process information using a computer. For many people with speech disabilities who rely on AAC, communication effectiveness determines personal achievement and is a function of selection rate. Evidence-based clinical practice relative to the determination of the most effective selection method requires data. This research provides preliminary evidence to support practice.

## METHOD

The Joystick to Mouse Adapter provides three modes of control: proportional pointing, proportional directed scanning, and a hybrid of the two. The Adaptive Switch Laboratories (ASL) Mouse Emulator provides switch-controlled two-speed on-axis and diagonal directed scanning.

Both can be driven by the Invacare Mk. IV power wheelchair control system. The test setup consisted of 1) the Mk. IV controller powered by a 24 volt DC power supply, 2) the Joystick to Mouse Adapter and IR receiver/mouse emulator, 3) the Invacare ECU adapter, 4) the ASL Mouse Emulator, and 5) a Windows computer with a 15" monitor.

Six subjects without disabilities were used in this study. The inclusion criteria included self-identification as having normal manual dexterity, at least 21 years old, normal vision after correction, normal hearing, a high school graduate, normal cognitive ability, and familiar with basic computer operation. For this study no subjects used powered wheelchairs for mobility.

The six subjects ranged in age from 25 to 55 and included both males and females. They were asked to perform two tasks using the four modes of control. The first task was a target acquisition exercise. The exercise was presented using Guide 2.0 performance measurement software. At the beginning of the exercise, a black circle appeared at the center of the screen. The subject held the cursor within this circle, and a 15 mm target symbol then appeared elsewhere on the computer screen. The subject would select the target with a 500 ms. dwell, then return the cursor to the center of the screen. Targets appeared at any of four distances from the center of the screen. Each subject performed three repetitions of the exercise, with 28 targets presented in a random order in each repetition. The Guide program was configured to present targets along the vertical and horizontal axes, and at randomly-selected off-axis locations. Auditory feedback was provided, with the computer volume control set to 10% of the linear range.

The second task was the transcription of text using onscreen keyboard software (WiViK Version 2.5, Prentke Romich Company, Wooster, OH) and Typing Instructor Version 11 (Individual Software, Pleasanton, CA). Each subject completed three drills for each condition.

## RESULTS

Tables 1 and 2 and Figures 1 and 2 present the individual and average performance of the subjects using the four modes of control for the target acquisition and typing tasks respectively.

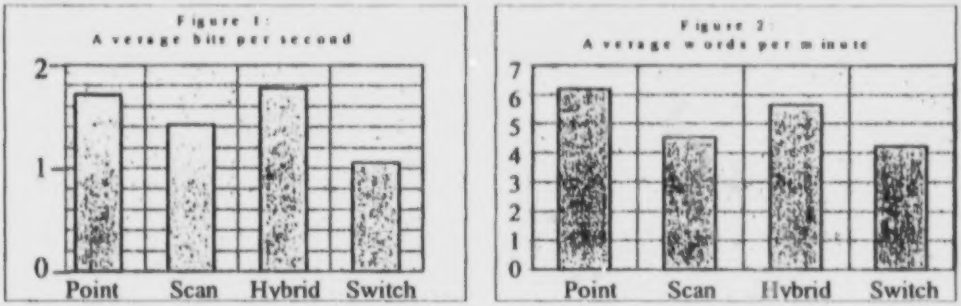
Table 1: Target Acquisition Performance in Bits Per Second

| Subject | JMA Pointing | JMA Scanning | JMA Hybrid | Switch Emulator |
|---|---|---|---|---|
| 1 | 1.65 | 1.30 | 1.78 | 1.03 |
| 2 | 1.83 | 1.60 | 2.05 | 1.07 |
| 3 | 2.09 | 1.25 | 2.26 | 1.05 |
| 4 | 1.75 | 1.83 | 1.68 | 1.18 |
| 5 | 1.56 | 1.38 | 1.27 | 1.05 |
| 6 | 1.40 | 1.18 | 1.62 | .93 |

Table 2: WiViK / Typing Instructor Performance in Words Per Minute

| Subject | JMA Pointing | JMA Scanning | JMA Hybrid | Switch Emulator |
|---|---|---|---|---|
| 1 | 5.8 | 4.0 | 4.0 | 2.7 |
| 2 | 8.7 | 4.0 | 9.0 | 5.0 |
| 3 | 8.3 | 5.0 | 7.3 | 5.0 |
| 4 | 6.3 | 6.3 | 6.3 | 3.7 |
| 5 | 4.3 | 4.3 | 3.0 | 4.3 |
| 6 | 3.7 | 3.7 | 4.3 | 4.7 |

Figures 1 and 2: Average performance for all subjects for the target acquisition and typing tasks. Arrows indicate range.



## DISCUSSION

Average performance for the pointing and hybrid modes was 65% and 40% faster than performance for the switch mode for the target acquisition and typing tasks respectively. To the degree that the joystick skills of the subjects of this study match those of people who use powered wheelchair joysticks and the tasks used in this study represent those of computer or AAC system requirements, this performance data can be used to guide in the selection of interfaces for converting wheelchair joystick position into mouse emulation. Further studies will be conducted including subjects who use powered wheelchairs with joystick control.

This preliminary study supports the practice of collecting quantifiable data to make clinical decisions regarding access methods to control assistive technology devices. The software programs provided summary measures in words per minute and bits per second that can be used to document performance. In this case, the use of automated approaches to performance measurement would provide ready access to data to compare various access strategies. This is not possible with traditional methods of observation. Trial data over time could be collected to document the learning curve and progress to support clinical decisions. These tools allow for the collection of data in accordance with the principles of evidence-based practice.

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# AUTOMATIC CUSTOMIZATION SOFTWARE FOR COMPUTER HEAD CONTROLS

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## ABSTRACT

Computer head controls provide an alternative means of computer access. However, some people are unable to effectively use head controls. Software was developed which automatically adjusts the interface sensitivity to the needs of a particular user. Sixteen novice head control users with spinal cord injury or multiple sclerosis used head controls with and without the automatic customization software. The automatic customization software was associated with increased speed in standardized icon selection exercises ($p<0.05$). A small increase in accuracy was also observed.

## BACKGROUND

Head-operated controls provide an alternative means of computer access. However, some people are unable to effectively use head controls due to neck movement limitations. One way to accommodate neck movement limitations is to alter the proportional gain of the head control system; that is, how far the cursor moves for a given head movement. Because each person's disability is unique, the ideal proportional gain will depend on the individual's strengths and limitations (1). It would be desirable if the computer could automatically select a person's optimal interface settings (2,3). Such a system could customize itself for a particular user, and readjust the gain as the user's needs change over time.

## RESEARCH QUESTION

Software was developed which measures a person's performance during a calibration procedure and automatically adjusts the proportional gain of a head control. The objective of this study was to determine whether use of such automatic customization software is associated with increased accuracy and speed in an icon selection task.

## METHOD

Sixteen subjects took part in this study (mean age 49.2 years, standard deviation 9.4 years). Eleven subjects had multiple sclerosis and five subjects had cervical spinal cord injuries. Subjects were not currently using head controls to operate computers.

This study involved two independent variables, head control software and head control hardware. In regard to software, subjects either used automatic customization software, described below, or a standard head control interface. Each subject experienced both software conditions, with the order of conditions randomly assigned. The two hardware conditions were a HeadMaster Plus™ head control (Prentke Romich Company, Wooster, OH) and a Tracker 2000™ (Madentec Ltd., Edmonton, Alberta, Canada). Two head control devices were used in order to determine whether any effect of the experimental software was independent of hardware. Each subject only experienced one hardware condition, randomly assigned to that subject.

An icon selection exercise was used to measure subjects' performance. Subjects selected 15 mm diameter circular targets using a dwell time of 500 ms. Performance was measured in terms of accuracy, throughput, and overshoot. Accuracy is the proportion of icons successfully selected. Throughput is a measure of speed, reported in bits per second. Overshoot is the maximum distance traveled beyond the icon as a percentage of the distance to the icon from the starting position.

The automatic customization procedure took place in five steps. The first step was used for practice, and the proportional gain was not adjusted. In the second step, the computer measured the subject's range of motion. Targets were presented at the edges of the screen, and subjects moved the cursor as close as possible to each target. The computer monitored the range of cursor movement in the horizontal and vertical directions and calculated a minimum proportional gain that would allow the subject to move the cursor to all corners of the screen.

During the third step, the software monitored the accuracy, throughput, and overshoot as the subject selected 28 targets in the icon selection exercise. The horizontal and vertical gains were adjusted according to the following rules:

1) If the accuracy was below 90% and the current gain is less than half the maximum gain, then increase the gain by a factor of 2;
2) If the accuracy was below 90% and the current gain is greater than half the maximum gain, then decrease the gain by a factor of 1/2;
3) If the accuracy was above 90% and either the throughput was less than 1.7 or the overshoot was greater than 10%, then decrease the gain by a factor of 1/2;
4) Otherwise, decrease the gain by a factor of 3/4.

Rules (1) and (3) were based on observations from previous research (1). Rule (2) was based on the assumption that, beyond a certain gain level, a low accuracy would be indicative of a subject's inability to make sufficiently fine cursor movements to select the target. Rule (4) was used to insure that the gain would change between Step Three and Step Four. Otherwise the software would not be able to compare the subject's performance at different sensitivity levels.

Table 1: Rules for adjusting gain in Calibration Step 4

| Change in Accuracy | Change in Throughput | Sensitivity adjustment, relative to previous adjustment |
|---|---|---|
| Increase | Increase | Repeat previous adjustment. |
| Increase | Decrease | Set gain halfway between current and previous levels |
| Decrease below 90% | Increase | Set gain halfway between current and previous levels |
| Decrease below 90% | Decrease | Reverse previous adjustment. |
| Remain above 90% | Increase | Repeat previous adjustment. |
| Remain above 90% | Decrease | Reverse previous adjustment. |

During the fourth step, gains were adjusted based on the change in performance between Steps Three and Four, as shown in Table 1. Following the fifth step, the software compared the accuracy and throughput across all five steps. The final gain was selected according to the following rules:

1) If accuracy was below 90% for all steps, select the gain associated with the highest accuracy;
2) Otherwise, consider only those gains associated with accuracy above 90%. From among these gains, select the gain associated with the highest throughput.

Improving accuracy was given a higher priority than improving throughput in order to first ensure that a person is able to access all areas of the screen, and only then improve his or her speed.

In the control condition, subjects performed a series of icon selection exercises equivalent to the calibration procedure, but the head control sensitivity was not adjusted. This was used to substitute for the extra practice which the subject would acquire during the calibration procedure.

For each software condition, each subject performed the calibration procedure or equivalent exercises. He or she then performed an additional 6 repetitions of the icon selection exercises at the same gain setting, with targets presented at 24 locations around the screen. The gain was either computer-selected (from the calibration procedure) or a standard gain (for the control condition).

Performance during these exercises was used for further analysis. When the subject had completed these steps for both the control condition and experimental software, he or she completed a brief questionnaire concerning the usefulness and ease of use of the head controls under each condition.

## RESULTS

Throughput, accuracy, and subject ratings of usability and ease of use are summarized for each software condition in Table 2. Subjects had significantly higher throughput when using the experimental software ($p<0.05$). Subjects tended to have higher accuracy with the experimental Software and to rate the experimental software as more usable and easier to use, but these differences were not significant.

Two factor analyses of variance were performed for the effect of head control hardware (HeadMaster v. Tracker). There was no significant effect of head control hardware on performance ($p>0.05$) and no significant interaction effects between hardware and software conditions.

Table 2: Comparison of performance measures between software conditions (mean ± standard deviation). Asterisks (*) denote significant differences ($p<0.05$ for paired Wilcoxon tests) compared to the control condition.

| | Control Condition | Adaptive Software |
|---|---|---|
| Throughput | 1.21 ± 0.56 bits/sec | **1.29 ± 0.63 bits/sec** * |
| Accuracy | 97.4 ± 7.2% | 98.6 ± 3.3% |
| Ease of Use<br>(5 is easiest) | 4.1 ± 1.0 | 4.2 ± 0.8 |
| Usability<br>(1 is most usable) | 1.6 ± 0.6 | 1.4 ± 0.6 |

## DISCUSSION

Software was developed which automatically adjusts the head control gain in response to a person's accuracy, throughput, and overshoot while performing pointing tasks. Subjects were able to perform significantly faster and with somewhat higher accuracy using sensitivity selected by the automatic customization software. Two subjects had a greater than 25% improvement in speed with the adaptive software. Such automatic customization software could make it easier for a person to initially access a computer, and could reconfigure the interface as the user's needs change over time. It would still be desirable for the computer-selected sensitivity to offer a larger improvement in performance for more subjects.

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# USER PERFORMANCE WITH SPEECH RECOGNITION SYSTEMS

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## ABSTRACT

This paper presents early results on the performance of automatic speech recognition (ASR) for current ASR users. Eight individuals performed a series of word processing and Windows tasks under two conditions: with and without speech. Total task time averaged 35% slower with speech than without ($p < 0.05$). The average rate for entering text, however, was approximately 13 wpm for either condition. Text entry rate with speech varied widely, ranging from 3 to 25 wpm. Users who had the fastest rates were those who employed the best correction strategies while using ASR.

## BACKGROUND

The number of people with disabilities trying speech recognition systems continues to grow, and the promise of ASR is enormous. While a variety of ASR applications have potential benefits for individuals with disabilities, the focus of this study is on the use of ASR for general-purpose computer access, particularly text entry. Table 1 summarizes published data on text transcription performance for able-bodied subjects [1,2,3].

| User Experience | Recog. Accuracy (%) | Text Entry Rate (wpm) |
|---|---|---|
| Initial Use | 85 – 93% | 14 |
| Extended Use | 94% | 25 – 30 |

**Table 1.** Performance of able-bodied users of automatic speech recognition systems. Text entry speeds include time required to correct recognition errors. The transcription rate for these subjects using the standard keyboard averaged 32.5 wpm.

Speeds on text entry tasks using speech input in these studies were generally slower than speeds on the same tasks using keyboard and mouse. However, it can be difficult to make a fair comparison to more commonly used methods such as the keyboard, since many of the subjects had already developed a high degree of skill with these methods. A more significant issue is that these data represent only a handful of able-bodied subjects, and we have found no studies employing users who have physical disabilities.

## RESEARCH QUESTIONS

The general goals of this three-year project are to understand how well ASR systems are meeting the needs of people with disabilities and to improve user performance with ASR systems. The specific goals of this study are to measure the performance that current ASR users achieve, compare this to non-speech input methods, and identify key factors that influence user-ASR performance.

## METHOD

Design. Subjects used each of two input conditions to perform a prescribed series of computer tasks: the "Speech-plus" condition involved the use of speech input, and the "No-speech" condition prohibited the use of speech input.

Subjects. Nine subjects have participated as of December 2001. All have physical disabilities that affect their ability to use the standard keyboard and mouse, and all had at least 6 months of experience using ASR. Eight of the subjects could perform the tasks with a non-speech alternative; seven of these typed directly on the standard keyboard, and one used an on-screen keyboard. One subject used *only* speech; his data are not included in the comparative analysis between conditions.

Procedure. Sessions occurred in the subject's home or office, on their own computer. Six word processing and Windows tasks were defined for each input condition. Two were text entry tasks: transcription of a paragraph from hardcopy and a short composition on a supplied topic. The remaining tasks included opening, saving, and moving files; simple text formatting; and browsing and creating folders. The tasks were identical for each condition, except that the transcription text and the composition topic were comparable but not the same. The order of input conditions was counterbalanced across subjects.

Instructions for each task were presented in hardcopy, one task per page. Subjects began a task when they were ready and proceeded one task at a time. In the Speech-plus condition, subjects entered text with speech, but they were also allowed to choose alternative methods, such as direct control of the mouse, to execute commands and make corrections. They were instructed to perform the tasks in the way that they "usually" do.

Data Collection and Analysis. The subject's computer screen and speech were recorded on videotape to allow for detailed analysis of user actions. Dependent variables were the total time across all six tasks, text entry rate, and recognition accuracy. Correction strategies used to fix recognition errors were also tracked. The text entry rate in words per minute (wpm) includes the time required to correct recognition mistakes. Paired t-tests were performed to compare performance with and without speech.

## RESULTS

The time required to perform all six tasks took an average of 35% longer, or approximately 4 extra minutes, in the Speech-plus condition as compared to No-speech ($p < 0.05$). Seven of the eight subjects required more time in the speech condition. The average speed of text entry, however, was the same for both conditions, at approximately 13 wpm. Half of the subjects were faster entering text with speech, and half were faster with their alternative method.

In the Speech-plus condition, performance varied widely between subjects, even though all subjects were long-term users and had unimpaired speech. Text entry rate with speech ranged from 3 to 25 wpm, with an average of 13.1 wpm. Recognition accuracy for text ranged from 72 to 94%, with an average of 83.5%.. Figure 1 shows the relationship between text entry rate and recognition accuracy, in which subjects who had higher recognition accuracy tended to have higher text entry rates, as would be expected.

The figure also reveals that subject performance fell roughly into two clusters. Group A, with 5 subjects, had better overall performance, with text entry rates at 10 wpm or faster and recognition accuracy of 90% or better. Group B, with 4 subjects, achieved text entry rates of 10 wpm or less and recognition accuracy of 75% or less.

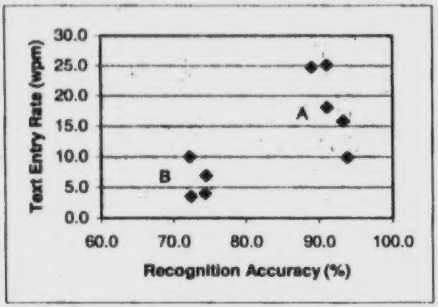

**Figure 1.** Text entry rate vs. recognition accuracy for 9 ASR users with physical disabilities.

## DISCUSSION

The current data suggest that a target of 90% recognition accuracy may be a key to success with ASR. The correction strategies employed by users may be critical to achieving that target [3]. Fixing ASR errors using the system's correction dialogue allows the system to improve its model of the user's voice, while correcting with the general purpose "Scratch That" command actually can degrade the voice model. Our results support this, as the higher-performing Group A subjects used "Scratch That" only about 10% of the time, while Group B subjects used it almost half the time.

The performance of these subjects overall was poorer than might be expected based on previous studies. Although all were long-term users, a significant portion of our subjects entered text more slowly and had worse recognition than the Initial Use subjects from Table 1 did after only an hour or two of ASR experience. We need to understand if this is simply an artifact of small sample size, or if it relates to a significant issue in delivering ASR to users with disabilities. We plan to collect data from 4 – 6 additional subjects to enhance the robustness of our understanding.

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# A METHOD FOR MEASURING CLIENT PERFORMANCE WITH SPEECH RECOGNITION

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## ABSTRACT

As part of a 3-year study on user performance with speech recognition systems, we are following new users of speech recognition over time, to understand the skill development process. Because we are taking multiple measurements on each individual, within a clinical context, we needed an assessment task that would be a good indicator of user performance, but could be conducted by a clinician in just a few minutes using a stopwatch, pencil, and paper. This paper presents our method and how it can be used by other clinicians who wish to measure their clients' performance.

## BACKGROUND

Automatic speech recognition (ASR) systems have the potential to enhance the comfort and productivity of computer users who have disabilities. However, while use of speech for human communication is natural, speaking successfully to a computer is not. Today's ASR systems can be used within a few minutes of installing the software, but anecdotal reports suggest that 30 – 50 hours of training and practice may be required for users to become proficient [1]. To better understand clients' progress toward proficiency with ASR, a simple method of measuring their performance over time is needed.

As part of our study on how speech recognition users develop skill with ASR, we have developed such a method. This has value to our project because it allows clinicians affiliated with the project to obtain the necessary data during their normal clinical activities. It may also be of value to other clinicians as a means of better understanding and documenting how well an ASR system is working for a particular client. For this reason, we present the basic aspects of our method for measuring user performance with ASR systems below. Full details and instructions for using the method can be found at our website, http://www.umrerc.engin.umich.edu, or by contacting the author.

## OBJECTIVE

The objective of this work was to develop a procedure that meaningfully measures user performance with speech recognition within a clinical context. This objective leads to the following design criteria:

1. Easy to learn for both the clinician and the client.
2. Can be done by the client at earliest stages of ASR use. That is, the task requires only basic skills that the client would typically learn right away.
3. Requires only a few minutes. Participating clinicians indicated that they would conduct the task if it took only 5 – 10 minutes out of the training session.
4. Requires no special tools or equipment.
5. Measures key indicators of client performance. While there are numerous performance measures that might be of interest, the brief nature of this task dictates that it focus on a subset of high significance.

## METHOD

Overview. Clients who are new to speech recognition often receive several training sessions with a clinician. This assessment task is designed to be used by the clinician within an ASR training session. The procedure consists of two primary phases: a dictation phase, followed by a correction phase. The purpose of the dictation phase is to measure the recognition accuracy the client is achieving with the ASR system, as well as to indicate the upper limit of text entry rate that might be achieved if there were no recognition errors. The purpose of the correction phase is to measure the client's true text entry rate, when the time required to correct recognition errors is taken into account.

Dictation Phase. In the dictation phase, clients dictate a short paragraph from hardcopy into a word processing program. They are instructed not to correct any recognition errors. The clinician times the duration of the dictation phase and records it on the data form. The output of the ASR system during the dictation is saved in a file.

Correction Phase. In the correction phase, clients make corrections to the output of the dictation phase, until it matches the transcription text as closely as possible. Clients are told that they may correct the errors in any way they choose. The clinician times the duration of the correction phase and saves the final output in a file.

Warmup. Prior to the paragraph dictation, clients can optionally perform a short warmup for the procedure on a single short sentence. This gets them used to the separation that the task requires between dictation and correction.

Test for Non-speech Input Method. Most clients can also use a method other than speech for input to their computer, such as mouthstick typing. In order to compare performance with and without speech, the assessment procedure includes an option for measuring performance with the non-speech input method. This has only one phase and involves transcribing and correcting a single sentence while the clinician records the elapsed time. If a client has used the non-speech method for quite a while, performance may be fairly stable, and this test may need to be performed only once or twice.

Texts. A series of 7 dictation texts have been developed for use with this procedure. This allows a different text to be used for each test. The texts range from 60 to 65 words long, and are matched to provide a consistent 6th grade reading level.

Data Collection and Analysis. During the test, the clinician records the times required for the dictation and correction phases and saves the output of each phase. After the test, the clinician reviews each output file and counts the errors. The recorded times and counted errors can then be entered into a spreadsheet which calculates the user's dictation speed, net text entry rate, and recognition accuracy. The dictation speed is the number of words dictated divided by the time required for the dictation phase. The net text entry rate is the number of correct words in the final output divided by the total time required for both the dictation and correction phases. The recognition accuracy is the number of correctly recognized words in the dictation output divided by the number of words in the dictation text.

## RESULTS

The measurement procedure appears to meet its design criteria for both clinicians and clients. Five people have successfully learned to conduct this procedure with clients, and eight clients have performed the task in clinical settings. Clients have been able to do so in their very first ASR training session. The procedure generally takes less than 10 minutes and requires only a stopwatch and paper forms.

## DISCUSSION

Limitations of the Method. The task focuses exclusively on text entry, and while that is a key component of user performance with speech recognition, it relates only indirectly to other tasks such as entering application commands or navigating Windows by voice. In addition, the task is fairly simple, so that it can be administered very early in the client's ASR experience. The simplicity of the text suggests that the resulting measures are akin to a "best-case" scenario, since performance may differ on more complex text.

Required Client Skills. Because the correction process is separated from the dictation process, the client must have the skills to fix errors at any time, not just immediately after they occur. With Dragon NaturallySpeaking, this requires the ability to use the "correct <specific words>" command, instead of relying solely on "correct that." For the clinicians who participated in this study, this skill is usually presented in the first training session, so it is a reasonable expectation of their clients. If this skill is not introduced in the first session, use of the assessment method can simply be delayed until it is presented.

A Caution. When we use this procedure, we are careful to minimize the "test-taking" aspects of it. We emphasize that the purpose is to understand how well the ASR system is working for the client, and not to gauge the client's abilities. Nonetheless, there is the risk with some clients that poor performance on, or even mere participation in, this procedure may produce anxiety and even decrease the client's enthusiasm for use of ASR. We have not seen this happen with any of the clients who have participated thus far, but clinicians need to be sensitive to the possibility.

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## ACKNOWLEDGMENTS

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# "ASSESSMENT OF COMPUTER TASK PERFORMANCE" WITH PAEDIATRICS AND LOW VISION

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## ABSTRACT

The "Assessment of Computer Task Performance" is a measurement instrument designed to evaluate a person's performance over time with a computer. It can be used with children and adults with motor impairments as well as with children with low vision. Its focus is on how the person is performing in terms of "speed" (time) and "accuracy" (4 point scale) when performing sequences of actions that result in a computer command. It is divided in 11 keyboard tasks and 10 mouse tasks. With children with low vision (n=22), the test shows good psychometric properties. As a clinical tool, it provides data to document the performance of all needed computer applications and to improve quality of prescription of assistive technology.

## BACKGROUND

Occupational therapists in school settings are increasingly solicited to aid the visually impaired clientele in using computers, but they face numerous challenges. There is a large selection of assistive technology (AT) related to computer use, and in order to choose the best equipment for each client, therapists must be able to try different options. Often, this must be done within a limited amount of time because of the need to be efficient and limit costs. In addition, therapists must ensure that the recommended equipment permits access to all needed computer applications, including word processing, Internet, games and educational software [1,2]. Literature yields three major categories of factors that impact performance in computer use with low vision: the user, the environment and the AT. Users such as children of pre-school age with low vision often show signs of lagging development both at the qualitative (ex. imprecise movements) and quantitative (ex. move less than other children) levels. Their main problems include aspects of postural balance, fine motor skills and perception [3]. They also encounter difficulties with penmanship; writing is difficult to read, of lesser quality and they write more slowly. A computer can compensate for the majority of these problems [3,4]. Regarding the environment of computer use, the difficulties encountered can be the strategies of training or due to technical considerations such as the distance between the eyes and the screen and the size of the screen display [4]. Regarding AT, shortcut keys in computers, changing Windows configuration of the screen (foreground and background color), font, feedback when a key is pressed, scrolling menus containing lists of actions, icons, cursor, dialog boxes, checkboxes codes and colors could all be modified (slowly, bigger, more contrast) to facilitate the recognition of elements on the screen [4].

## PROBLEM STATEMENT

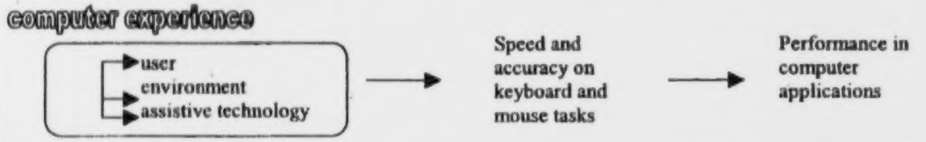
Unfortunately, literature related to assessment tools for computer access is specific to a disability (such as cerebral palsy) and can not be generalized to the majority of persons with disabilities.

Studies on a specific AT or methods using lists of different devices may become obsolete as new modes of access are constantly being developed. In addition, the tasks used to compare access modes are limited to specific actions and may not represent the general use of a computer. In order to resolve these problems, the "Assessment of Computer Task Performance" was developed for adults and children with motor impairment [1,2] and for children with low vision [5].

## APPROACH

*Conceptual basis of the instrument.* – The word performance means «beginning and carrying through completion». As shown in Figure 1, the relations between variables involved in computer experience can be considered and presented linearly. The performance is conceived as a reaction of speed and accuracy on mouse and keyboard tasks, tasks that are required for any computer applications. Their control depends upon the user interaction with environment and AT as stated by the model of matching person and technology [6]. The "Assessment of Computer Task Performance" has been developed to evaluate performance, both in terms of speed and accuracy, when using the actions or sequences of actions that result in a computer command.

**Figure 1: Model involving performance in computer applications**


computer experience
user
environment
assistive technology
Speed and accuracy on keyboard and mouse tasks
Performance in computer applications

*Description of the Test.-* The test includes 21 keyboard and mouse tasks, divided in preliminary and timed standardized tasks (See Appendix). The preliminary tasks determine whether a client needs AT to complete the test or at least some part of it (e.g.: screen magnification, stickers of enlarged letters for the keyboard, deluxe cursor, screen size, Windows display settings, settings in Word and cursor speed settings). Each item is scored using a 4 point Likert scale graded as: *completion, completion with errors, partial completion and unable to perform*. The type and number of errors are used to categorize the participant's performance level. The precision of performed tasks that involve mouse functions as well as certain keyboard tasks are recorded. Observations should be noted for each task that is: AT used, posture, eye-to-screen distance, copyholder for reading material, compensation for deficits or any other factor that could interfere with accomplishing the task. The test manual provides suggestions of AT for those who are unable to perform at a task

*Psychometric properties.-* The test had been validated in French (F) and in English (E) with children without (21 F; 20 E) and with motor impairment (17 F; 26 E), with adults without (19 F; 29 E) and with motor impairments (17 F; 24 E) [1, 2]. Finally, the French language test was also administered to 22 of the 23 children aged between four and ten years being treated for low vision in two regions of Quebec. The participant selection criteria were: 1) low vision: acuity between 6/21 and 6/90 or field of vision less than 60°; 2) cognitively intact; 3) aged between four and ten years; 4) no diagnosis of motor impairment. The reliability of four standardized tasks was high (Intraclass Correlation Coefficient ranged from 0.79 to 0.99). There is moderate internal consistency for the global test [5].

## DISCUSSION

The study faithfully represents the population of children with low vision in Quebec area. The test-retest reliability of each participant was carried out with the same equipment configuration, instructions and experimented therapist. Psychometric properties are better with the adults [1,2] because of the difficulty to standardize some tasks with children, especially the short ones. As a clinical or research tool, the Assessment of Computer Task Performance provides data to document: the realization of all needed computer applications, the improvement after a training period, the comparison of performance results using different AT or between different user groups and settings.

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## Appendix [1]

*Preliminary* KEYBOARD tasks :

1. Covering the extent of keyboard
2. Making 2 or 3 simultaneous strikes
3. Double strikes and complex keys
4. Triple Striking
5. Holding down a key

*Preliminary* MOUSE tasks :

1. Using a mouse
2. Dragging and dropping an icon along a curved path
3. Dragging and dropping an icon along a right angle path
4. Dragging and dropping an icon along a short course, many consecutive times
5. Moving in document using the vertical scroll bar and scroll arrows
6. Moving in passing menus
7. Use of windows

*Timed standardized* KEYBOARD tasks:

1. Repeating keys
2. Double keys
3. Move the cursor with the keyboard keys
4. Typing the accents over vowels
5. Writing out the alphabet (no model)
6. Writing sentences

*Timed standardized* MOUSE tasks :

1. Moving the mouse pointer along a path and clicking at a precise location
2. Stopping the mouse pointer at precise locations and double-clicking
3. Changing a window's size using the edges

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[1] All tasks are detailed in the guidelines available on www.irdpq.qc.ca, new technology section

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# AN ASSISTIVE TECHNOLOGY OUTCOMES PRIMER

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## ABSTRACT

Interest in assistive technology outcomes has increased markedly in recent years. While the Assistive Technology Outcomes Listserv (http://www.utoronto.ca/atrc/reference/atoutcomes) is a recognized authority and repository for information on this topic, individuals new to the topic have a difficulty time locating an accessible introduction and overview of the topic of assistive technology outcomes. The purpose of this paper is to describe an innovative series of projects conducted under the auspices of the Assistive Technology Outcomes Management Systems (ATOMS) Project at the University of Wisconsin of Milwaukee.

## BACKGROUND

Given the interdiscipinary nature of assistive technology and the relatively recent interest in assistive technology outcomes, individuals looking for information on this topic are likely to have a difficult time locating relevant information given the scatter of the literature. In addition, given differing perspectives on the nature of outcomes, some who are new to the field may have a difficult time shorting out conflicting perspectives, identifying key definitions, or linking one article within a larger professional context.

The Assistive Technology Outcomes Management Systems (ATOMS) Project at the University of Wisconsin of Milwaukee is a new NIDRR-funded grant designed to study assistive technology outcome measurement and instrumentation. In this paper, we describe three initial projects to address the need for cognitively accessible introductions to the topic of assistive technology outcomes.

## OBJECTIVE

To create a cognitively accessible introduction to the topic of assistive technology outcomes, the ATOMS Project created three related web-based products: (a) an AT Outcomes Primer, (b) an interactive "Test Your Knowledge of AT Outcomes" Quiz; and (c) materials and resources to support Collegial Study Groups seeking to understand more about assistive technology outcomes.

## APPROACH

To create the initial series of products for individuals and groups to explore issues involved in the topic of assistive technology outcomes, our staff drafted materials for internal review which were subsequently reviewed by our advisory board and piloted with students at the University of Wisconsin-Milwaukee. Each of the following web-based products are located at the ATOMS Project web site: http://atoms.uwm.edu.

### An Assistive Technology Outcomes Primer

This first product was designed to serve as a self-directed reading list to introduce interested individuals to key works in the professional knowledge base on assistive technology outcomes. This list is organized by type of materials (books, selected articles, special issues of journals, and web sites). We anticipated interested individuals using this reading list to validate their own experience and to seek articles missing from a basic core collection of readings and resources. We expect that college instructors and workshop presenters will use this list as they construct required and supplemental reading lists.

### Interactive "Test Your Knowledge of AT Outcomes" Quiz

Previous work with teachers and technology specialists on technology integration have suggested to us the value of electronic quizzes as a means of testing one's own knowledge or for use following inservice workshops. As a result, the ATOMS staff felt it was appropriate to consider this type of tool for use as a stand-alone resource or one that could be used in conjunction with the readings found in the Assistive Technology Primer.

This second product was designed using an electronic quiz program developed by the University of Kansas called "QuizStar." Users of the free web-based software provide their email address to access a quiz. The quiz is composed of true/false, short answer, and multiple choice items. Upon completion of the quiz, users are provided with their score and feedback on each item.

### Collegial Study Group on Assistive Technology Outcomes

Whereas the first two projects focus on the individual as the unit of change, organizational change only occurs when a common vision guides the efforts of a group of individuals. One tool increasingly used in education for the purpose of fostering collaborative change involves the use of collegial study groups (Edyburn & Gardner, 1999; Herner & Higgins, 2000; Sanacore, 1993). As a result, we perceived the need to create a resource that enable organizations to move forward by gaining a critical mass of voices that shared a common vision concerning assistive technology outcomes.

This project provides an electronic version of the collegial study group materials and resources assembled by Edyburn (2000). The intent is to bridge the theoretical and the practical through the use of collegial study groups as a professional development and change strategy. A four-session study group is outlined using readings and online explorations to provide interested groups of professionals with an experience in discovering the power, impact, and value of assistive technology for individuals with disabilities. A guide for each session includes: preparation activities, discussion questions, and session outcomes.

## RESULTS

As the materials have been completed during the fall 2001 semester, the ATOMS project seeks to collect implementation data during the spring 2002 semester in order to collect formative and summative data on these three projects. Results of these projects will be provided at the ATOMS web site (http://atoms.uwm.edu) as they become available.

## DISCUSSION

The challenge of meeting the needs of inservice professionals at a time when the knowledge base is emerging is a critical need the ATOMS Project sought to address through a series of three related web-based products. Early evidence suggests that these efforts will be valued by the profession.

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# AccessX and OnScreen Keyboard for LINUX

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## Abstract

The LINUX operating system is a popular version of the Unix operating system. This paper discusses recent accessibility improvements for LINUX by enabling access to the X-Windows Accessibility features and through the development of an onscreen keyboard. These improvements are all open source and freely available.

## Introduction

LINUX is a popular open source version of the UNIX operating system. LINUX is a collection of a number of open source projects including XFree86 (X-Windows) and GNOME (X-Windows based GUI). LINUX provides a very robust operating system and is becoming a much more widely used operating system in the general public throughout the world. LINUX has been developed using an open software model with people from the LINUX community contributing software that is essentially available for free to anyone. Very little of the current software contributed to the LINUX community has been designed to improve the accessibility of LINUX by people with disabilities. Even built-in X-Windows accessibility features like mouse keys and sticky keys were essentially broken until recent revisions of Xfree86 corrected the keyboard timing problem. Other advanced accessibility features are not available to people with more severe disabilities.

## AccessX

The DACX group coordinated by the Trace Research and Development Center at the University of Wisconsin and major developers of UNIX computer hardware and operating systems formed a group to create basic accessibility features for the X-Windows graphical user interface management system (1, 2). The group defined specifications for keyboard and mouse key accessibility features for the X-Windows keyboard extensions. These were included in the final releases of the X-Windows operating system (3).

LINUX and XFree86 (4) are open source versions of the UNIX operating system and the X-Window graphical user interface. Most LINUX distributions are designed for Intel based PC compatible computer systems. The open source version X-Windows that was the basis for XFree86 did not include a control panel utility for enabling and setting the AccessX features of the X-Windows keyboard extensions. A computer science senior design project at UIUC (4) developed a prototype graphical control panel and a set of command line utilities to enable and set the AccessX features of XFree86. During this project the senior design group discovered problems in setting the timing values for slow keys, repeat keys and the pointer movement speed for mouse keys. It became apparent that there was a bug in the X-Windows system for LINUX. The bug was traced to the hardware keyboard repeat generated by PC keyboards. PC keyboards repeat the key down codes, during keyboard repeats, which confused the timers used to determine keyboard hold times, repeat rates and mouse movement speed. The problems were also found by others wanting to use the access features with Xfree86 and the various fixes were proposed to the Xfree86 development people (5). The problem was corrected in recent releases of Xfree86. The control panel was submitted to the X-Consortium to be considered to be included in future releases of X-Windows. The XFree86 AccessX utilities are compatible with SUN configuration files. This is important to for users of multiple computer systems to share their settings between computers. The following is a table of AccessX accessibility features.

Table of Features Provided by AccessX

| Feature | Description |
|---|---|
| Mouse Keys | Allows pointer operations to be emulated through keystrokes on the numeric keypad. |
| Bounce Keys | Set the time required before a key repeat starts |
| Sticky Keys | Allow single finger operation of the keyboard with momentary or locked functionality for modifier keys (shift, control and alt) |
| Slow Keys | Set the amount of time required for a key to be pressed before it generates a keystroke |
| Repeat Keys | Set the rate a key will be repeated if it is continuously held down |
| Timeout | The length of time the computer will wait, without user input, until it turns off accessibility features |

## On Screen Keyboard

People who cannot use the standard keyboard can sometimes use an on-screen keyboard. An on-screen keyboard renders the images the keys of a standard (or custom) keyboard on the graphical computer display. The user can use the standard pointing device (or any system that can emulate the standard pointing device) to select keys from the graphical keyboard and send the key presses to other programs running in the X-Windows systems. A Computer Science Senior design group at UIUC has developed an on-screen keyboard for the X-Windows and GNOME (6) operating systems. The keyboard allows the user to adjust both the arrangement and the colors used to render the keys on the on screen keyboard. Users can use a standard text editor to edit the keyboard layout files to create their own custom keyboard arrangements and character mappings. Users can select keys they are pointing to by either a pointer click command or by holding the pointer on a particular key for a user defined period of time. The keyboard configuration file is separate from the color configuration files to make it easier for users to share keyboard and color configuration information.

The computer science students have developed two different versions of the on-screen keyboard. One version uses only the X-Windows widget set (X-Windows graphic primitives), so that it can potentially be included in the standard X-Windows software distribution. The other version uses the graphical style and resources of the GNOME Windowing environment. The support of GNOME by Sun for their graphical user interface for the Solaris operating system, and the use of GNOME in many distributions of the LINUX operating system has moved GNOME to the forefront of the X-Windows window management and development system. Functionally the two keyboards will be equivalent, but the GNOME keyboard will provide the GNOME styling and better help features. GNOME is also a much easier environment to develop software for the X-Windows environment and therefore is easier to extend functionalities of the GNOME keyboard in an open source environment. In the future functionalities could include a word prediction and macro feature capabilities.

## More Information

Information on the AccessX control panel and On-Screen keyboard are available at the following web sites. The site also contains information on how repair the bug in earlier version of XFree86.

AccessX information: http://www.rehab.uiuc.edu/accessx

OnScreen Keyboard: http://slappy.cs.uiuc.edu/fall01/team3/index.shtml

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# PILOT STUDY ON USER PERFORMANCE WITH SPEECH RECOGNITION SYSTEMS

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## ABSTRACT

As part of a three-year study on user performance with speech recognition systems, we have been investigating methods of measuring client performance over time. This paper presents results of a pilot study using one of these methods. One able-bodied subject dictated text using Dragon NaturallySpeaking for 11 test sessions. Results show a clear improvement in skill over time and also suggest that text entry rate may depend strongly on the specific type of task being performed.

## BACKGROUND

Automatic speech recognition (ASR) systems have the potential to enhance the productivity and comfort of computer users who have disabilities. However, little is known about how well ASR is fulfilling this potential. Popular reviews of such systems suggest that users can employ natural speech at their natural pace, with resulting dictation speed of up to 150 wpm [1], while scientific studies on able-bodied subjects suggest that 14 – 30 wpm may be a more reasonable expectation [2]. To investigate how well ASR works specifically for users who have physical disabilities, we developed a simple method for measuring client performance with ASR over time. To test the feasibility of the method, we performed a single case pilot study with an able-bodied individual.

## RESEARCH GOALS

This work is an informal pilot study for research that is investigating the learning curve associated with automatic speech recognition and the factors involved in developing proficiency with ASR. The specific objective of this pilot study was to evaluate a measurement method for possible use in the main study. Within this objective, we wanted to assess the ease of using the method, to gauge the amount of practice necessary for a subject to become proficient with ASR, and to get some sense for how changes to the measurement task might influence user performance.

## METHODS

Subject. The subject, S1, was an able-bodied engineering undergraduate at the University of Michigan. The subject had no prior experience with speech recognition software, but did have many years of experience with computer applications and programming.

Initial Training. Before starting the testing, S1 went through the standard enrollment process for Dragon Naturally Speaking and followed the tutorial. She was also oriented to the measurement method and practiced using it to take measurements on herself.

Testing. Following initial training, the subject then entered text using automatic speech recognition for 11 trials, under three different text conditions: Simple Transcription (Trials 1 – 6), Complex Transcription (Trials 7 – 9), and Composition (Trials 10 and 11). Trials occurred twice a week, and were preceded by approximately one-half hour of practice using Dragon NaturallySpeaking.

Trials 1 – 9 shared a common measurement method. The details of the measurement method are provided in a companion paper [3], but are briefly described here. Each trial consisted of a dictation phase, in which no recognition errors were corrected, and a correction phase, in which S1 fixed any recognition errors until the text was accurate. The text output in each phase was saved to a file for analysis of errors, and the time required for each phase was recorded with a stopwatch.

The task for the Simple Transcription trials was to dictate a short paragraph from hardcopy. Paragraphs were different for each trial, but were matched for length (60 – 65 words) and reading level (6th grade). For Complex Transcription trials, the texts were more complex. They were longer, at a higher reading level, and included proper nouns, numbers and a range of punctuation.

The Free Composition trials involved composition of text on a supplied topic. For these trials, the stopwatch measurement method was not used, because it was awkward to enforce a strict separation between dictation and correction when there was no hardcopy text available for reference. Instead, these trials were videotaped for later analysis.

*Data Analysis.* Measures of dictation speed, net text entry rate, and recognition accuracy were calculated for each trial. Dictation speed represents how quickly S1 spoke during the dictation phase. Net text entry rate represents the true text entry speed, in which the time required to correct recognition errors is taken into account. The recognition accuracy represents the percentage of words spoken that were recognized correctly by Dragon NaturallySpeaking.

## RESULTS

The results of the pilot study are shown in Figures 1 and 2. The dictation speed data show that S1 spoke at approximately 100 words per minute (wpm), regardless of text type. In contrast, the net text entry rate varied considerably. For simple text, text entry rate improved from about 10 to over 60 wpm over the six trials. Dictating complex text was associated with a drop in text entry rate, to around 30 wpm. Composition decreased rate even further, to an average of 18 wpm.

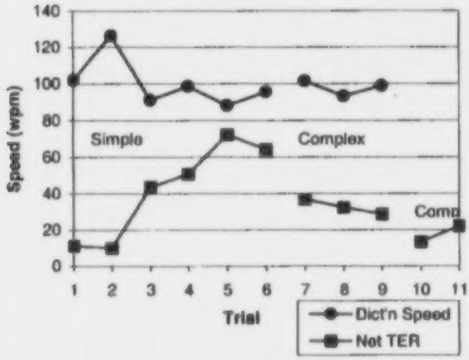

**Figure 1.** Dictation speed and net text entry rate (TER) for S1 across 11 trials.

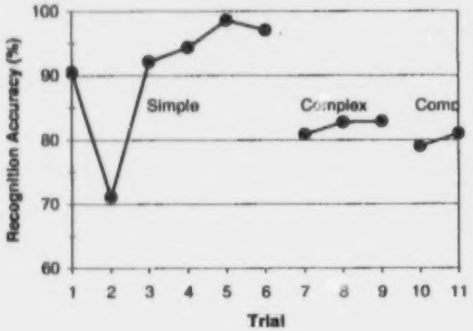

**Figure 2.** Recognition accuracy for S1 across 11 trials.

Figure 2 shows the recognition accuracy that S1 achieved. For simple text, accuracy was quite good overall, at 90% or better, except for Trial 2. It improved steadily over these trials as well, resulting in nearly perfect recognition in Trials 5 and 6. A drop in recognition accuracy can be seen in the complex text and free composition trials, holding fairly steady at around 80%.

## DISCUSSION

Through this pilot study, we gained confidence in our measurement method and learned more about its limitations. While the separation between dictation and correction phases is the key to the method's ease and efficiency, we found that it worked well only for text transcription, rather than free composition. We verified that the Simple Transcription task was geared at an appropriate level for beginning ASR users, exhibiting neither a floor or ceiling effect. We also learned that consistency between trials in the measurement task is necessary to avoid confounding factors, since changes in the text characteristics can have marked effects on user performance. Finally, our results suggested that the method would be easy for clinicians to use in the field, both in terms of time and number of steps required.

While the main goal of the pilot was to evaluate the measurement method for the main study, the data did provide some interesting empirical findings. First, they suggest that at least for some individuals, such as S1, fast text entry rates can be achieved with ASR within a fairly short time. Even the slower rates with more complex text, at 30 – 40 wpm, are comparable to typical speeds achieved with the standard keyboard [2]. The fact that text composition was slower is consistent with other studies [2]. Because the recognition accuracy was about the same in the composition trials as for complex text, the added time required for composition was most likely due to the time involved in deciding what to say.

Additionally, the results suggest that text entry rate with ASR may be sensitive to small changes in recognition accuracy. For example, across Trials 3 – 6, an increase in accuracy of about 5 percentage points was associated with an increase in text entry rate of about 20 wpm. Recognition errors take so long to correct, relative to dictation speed, that even eliminating one or two of them over the course of a paragraph can make a big difference. Text entry rate is not completely dependent on recognition accuracy, however. For example, in Trial 1, accuracy of 90% yielded a text entry rate of only about 10 wpm, while in Trial 7, accuracy of only 80% resulted in text entry rate of 35 wpm. The difference may be due to a greater efficiency in correcting errors that comes with skill development. These factors will be investigated further in the main study.

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# INVESTIGATING RELATIONSHIPS BETWEEN USER PERFORMANCE AND SCAN DELAYS IN AIDS THAT SCAN

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## ABSTRACT

Persons with severe physical disabilities may often operate electronic devices using a single switch in concert with an indirect selection technique such as scanning. We have examined how measurements of user performance such as reaction time relate to the user's perception of scanning delays.

## BACKGROUND

Persons with severe physical disabilities are often only able to operate electronic aids such as communication aids or computers by using the scanning selection technique along with a single switch. Users are frustrated whenever the scan delay is either too fast or too slow; however, no commercial aid currently monitors the user's performance in order to adjust the scan delay automatically. Though researchers have previously attempted to develop a scanning technique that automatically adjusts speed as the user in his or her ability to operate the scan [1] [2] [3], none have thoroughly investigated the relationships between the user's perception of the scan delay and measures of their performance.

## RESEARCH QUESTION

The objective of this study was to evaluate the relationship between the participant's perception of scan delays and several measures of performance, including best throughput, reaction time, ratio of reaction time to scanning delay, and errors.

## METHODS

We developed a simulation of the row-column scan technique using Microsoft Visual Basic 6 on a Compaq Presario desktop computer running Windows 98. The left mouse button of the computer simulated the action of the single switch. The selection set was a six by five matrix composed of 26 English letters in alphabetic order, a period character, and a space character. We designed the simulation so that the activation of the single switch started the scan, which would not stop until the task was completed.

We conducted these experiments with nine non-disabled participants, consisting of five males and four females ranging in age from mid-twenties to mid-eighties. The task of each participant was to compose the sentence "The quick brown fox jumps over a lazy dog." with the row-column scanning aid simulation. To exclude the influence of the time that the participants spent on figuring out the next character in the sentence, a box above the selection matrix displayed the next letter in the sentence the participant needed to enter. The tests with each participant began with a scan delay of one second. When the participant finished the sentence, he or she was asked to judge the scan delay by selecting one of the following five comments: "Much too slow", "A little too slow", "Comfortable", "A little too fast", "Much too fast". The test was then repeated with the scan delay decreased by 20%. Testing continued with the scan delay decreasing by 20% from the previous trial until the participant judged that he or she would not able to finish the composing task.

During testing, the scanning aid simulation recorded the time, the number of the currently-highlighted row or column, and details on the accuracy of the selection (correct, incorrect due to anticipation, etc.). The program automatically exported the data into a spreadsheet.

## RESULTS

Table 1 shows summary results for the trials. For each participant, the table compares the best time to complete the trial with the ratio of reaction time to scanning delay, selection errors, and the participant's perception of the scan delay.

| Participant | Best Time (sec) | RT/SD | Selection Errors | Perception |
|---|---|---|---|---|
| 1 | 130.9 | 0.67 | 2 | LTF |
| 2 | 147.7 | 0.69 | 5 | MTF |
| 3 | 140.2 | 0.68 | 3 | LTF |
| 4 | 222.4 | 0.59 | 3 | LTF |
| 5 | 174.0 | 0.58 | 11 | MTF |
| 6 | 120.6 | 0.59 | 0 | MTF |
| 7 | 117.2 | 0.70 | 2 | LTF |
| 8 | 277.6 | 0.56 | 1 | LTF |
| 9 | 456.2 | 0.61 | 4 | LTF |
| Mean | 198.5 | 0.63 | 3.4 | |
| SD | 110.2 | 0.05 | 3.2 | |

Table 1. Summary Results for User Perception Tests of Varying Scan Delays. Note that LTF = "a little too fast" while MTF = "much too fast".

Measurements of values of human performance summarized for the tests in which each participant completed the trials in the shortest amount of time widely among participants. The best time that each participant took to complete the experiment ranged from 117.2 seconds to 456.2 seconds. Selection errors also varied, with number of errors ranging from 0 to 11. However, the ratio of reaction time to scan delay only varied from 0.56 to 0.70.

## DISCUSSION

Though reaction time and selection errors seem to vary too widely among participants to be used as primary indicators of optimum scan delay, the results of these tests suggest that the optimum scan delay is one at which each user's reaction time is equal to 63% of the scan delay. This number agrees closely with the value of 65% reported by Lesher, Higgenbotham, and Moulton (3) as a factor used to decrease scan delays.

A matter of concern is the varying user perceptions of the scan delays that provided the best performance for each user. Each user noted that the scanning delay seemed to be either "a little too fast" or "much too fast". Further work will determine whether an algorithm that monitors user performance and adjusts scanning delays automatically should favor delays that provide best performance (i.e., best throughput) at the expense of user comfort.

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# Environmental Accommodation
## (Topic 4)

# FRAMEWORK FOR SYSTEMATIC EVALUATION OF JOB, WORKER, AND INTERVENTION COMBINATIONS

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## ABSTRACT

In order to create a decision support system to assist rehab professionals in making return to work decisions, a framework to systematically evaluate the interactions between job, worker, and intervention attributes is needed. This paper investigates these interactions by examining case studies involving an echocardiographer, phlebotomist, and specimen handler. The example ergonomic evaluations are presented along with lessons learned.

## BACKGROUND

Temporary work disability due to occupational injuries and illnesses is a concern since work related musculoskeletal disorders are a significant cause of lost work days. In 1999, there were 582,340 reported cases of musculoskeletal disorders that resulted in days away from work.[1] Rehab caseloads are increasing, resulting in less time to deal with individual cases, including cases of work related musculoskeletal disorders, therefore there is increased interest in developing computer programs that assist in the display and analysis of the complex data (referred to as decision support systems[2]) The first step to designing a decision support system is to identify the attributes, objectives, and goals that the decision-makers are interested in. In return to work decisions, job and worker characteristics are the main attributes of concern and the goal is to determine if a job is appropriate for a worker or if gaps exist between the job demands and worker abilities. If gaps exist that are barriers to work then an additional goal is to eliminate these gaps through the use of appropriate interventions. In order for a computer system to assist in solving these problems, the interactions between job and worker characteristics need to be explicitly defined.

## OBJECTIVE

This paper uses three typical support jobs found in a hospital setting to investigate the data and thought processes inherent in comparing worker attributes with job characteristics. Investigating the data and thought processes will assist in explicitly defining the important interactions between job and worker characteristics.

## METHOD

The example jobs and workers are summarized in Table 1. All available data is not displayed in the table due to space restrictions. The ergonomic ratings for each job are listed in the first row of each example. The ergonomic ratings were obtained by videotaping the jobs and analyzing the videos to rate various ergonomic risk factors on 10 point scales developed by Latko, et al.[3] The scales are based on 0-3 Low (none/minimal or neutral posture), 4-6 Medium, and 7-10 High (maximal or extent of range of motion). More details on the job analysis methods can be found in Streilein, et al.[4]

Workers were interviewed and asked to list clinical diagnoses (if any) and in what parts of the body they were experiencing pain. This is summarized in the first column of the second row of each example. The rest of the second row was generated from a literature review to determine which risk factors are associated with which diagnoses. If there was no clinical diagnosis and only non-specific discomfort, the second row was generated by specifying the body parts where the worker was experiencing discomfort.

FRAMEWORK FOR EVALUATION OF JOBS

The job and worker characteristics were compared to determine which risk factors are of concern for a particular job/worker pairing. This was done by manually comparing the job and worker characteristics. Interventions were then brainstormed for any identified gaps in the job/worker pairings. Ergonomists then predicted what effect the interventions would have on the ergonomic ratings. The job with interventions was then compared to the worker characteristics to determine if any areas of concern remain. Sometimes all areas of concern could not be eliminated due to limitation in current technology and/or the nature of the job tasks.

## DISCUSSION

The exercise of systematically comparing job and worker attributes manually revealed several areas where computer assistance could be useful including: helping to identify gaps between worker and job characteristics and narrowing lists of interventions from all available interventions.

In order to develop a decision support system to assist in these decisions, several types of expert knowledge need to be elicited from professionals in various fields. Information on the relationship between various diagnoses and ergonomic risk factors needs to be quantified by medical professionals. Consensus on what level of ergonomic risk is acceptable for various diagnoses or worker abilities needs to be established. Information on the effect of interventions on various risk factors and in what contexts various interventions can be used needs to be documented. These are pieces of information that rehab professionals have learned through course work or on the job experience that a successful decision support system will need to incorporate.

Several lessons can also be taken away from these cases, which were used to help determine what information will be needed to create a decision support system for return to work decisions. The ergonomic evaluation of these jobs revealed several common threads. Where adjustable equipment was available the workers did not adjust or know how to adjust the equipment. This highlights the need for involving workers in the ergonomic process and including worker training as part of ergonomic solutions. Some jobs will have a high hand activity level regardless of interventions. An example is the echocardiographer since current technology requires the worker to hold the probe for extended periods of time. Until a new machine or technique is created, little can be done to reduce their hand activity level. The hand activity level of the specimen handler is also unlikely to decrease significantly unless major job content changes are introduced due to the sheer volume of work that is required. Unlike hand activity level, in most cases extreme and awkward postures can be reduced or eliminated by applying ergonomic principles. In the jobs examined in this paper, taking the time to carefully rearrange and adjust the workstations should reduce most of the awkward postures.

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**Table 1: Job, Case, and Intervention summary** (Line 1 of each example lists ergonomic ratings for job, line 2 highlights areas of concern for individual with diagnosis shown, lines 4 (and more) show what effect the intervention is predicted to have on the ergonomic ratings, last line shows if there are still areas of concern)

| Job / Diagnosis / Interventions / Issues | Hand Activity Level | Hand Force | Posture | | | | | | | Contact Stress | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Flex/ Ext | Radial/ Ulnar | Forearm | Elbow | Shoulder | Neck | Back | Finger/ Hand | Wrist/ Palm | Forearm | Elbow |
| **Example 1** | | | | | | | | | | | | | |
| **Echocardiographer** | 7 | 2, 1.5 | 8, 4 | 9, 2 | 8, 6 | 8, 6 | 8, 5 | 6, 3 | 7, 4 | 3, 2 | 3, 2 | 2, 1 | 1, 1 |
| Non-specific pain in back, neck, R shoulder/arm/wrist | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | |
| Issue for job/worker pair? | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes | No | No | No | No |
| Reposition monitor | | | | | | | | ↓ | ↓ | | | | |
| Specialized bed | | | ↓ | ↓ | | | ↓ | | ↓ | | | | |
| Issue after interventions? | Yes | Yes | No | No | - | - | No | No | No | - | - | - | - |
| **Example 2** | | | | | | | | | | | | | |
| **Phlebotomist** | 5 | 3, 1 | 3, 1 | 9, 5 | 7, 2 | 5, 2 | 6, 1 | 4, 3 | 3, 2 | 2, 1 | 0 | 0 | 0 |
| Non-specific pain in back, neck, and R shoulder | | | | | | | ✓ | ✓ | ✓ | | | | |
| Issue for job/worker pair? | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No | No |
| Rearrange workstation | | | | | | | ↓ | ↓ | ↓ | | | | |
| Issue after interventions? | - | - | - | - | - | - | No | No | No | - | - | - | - |
| **Example 3** | | | | | | | | | | | | | |
| **Specimen Handler** | 7 | 3, 1 | 3, 1 | 3, 1 | 7, 3 | 5, 3 | 6, 2 | 4, 3 | 3, 2 | 2, 1 | 2, 1 | 2, 1 | 0, 0 |
| DeQuervains (wrist pain) | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | | | |
| Issue for job/worker pair? | Yes | Yes | No | No | No | No | No | No | No | No | No | No | No |
| Rearrange workstation to limit reaches (including tilting holding bins) | | | ↓ | ↓ | | | ↓ | | ↓ | | | | |
| Automatic bag opener | ↓ | ↓ | ↓ | ↓ | | | | | | | | | |
| Issue after interventions? | No | No | - | - | - | - | - | - | - | No | - | - | - |

Picture 1: Echocardiographer

Picture 2: Phlebotomist

Picture 3: Phlebotomist

Picture 4: Specimen Handler

# IMPLEMENTATION OF ERGONOMIC INTERVENTIONS IN OFFICE ENVIRONMENTS: A FOLLOW-UP REVIEW

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## ABSTRACT

Ergonomic workplace assessments and worker interviews were completed for workers with musculoskeletal disorders and other disabilities. Recommendations for ergonomic interventions were provided to the workers. Follow-up phone interviews were conducted with 22 workers. In addition, worksite evaluations and ergonomic assessments were completed for 5 workers. The jobs of the workers in this study were administrative support and professional. At least one intervention was implemented by 21 of the workers participating in the follow-up study. The types of interventions implemented included work methods changes and new equipment such as keyboards, monitor stands, touch pads, arm rests, carts and many others. A total of 99 interventions were implemented.

## OBJECTIVE

Both ergonomic job analysis and implementation of interventions are often used by employers to reduce identified work-related risk factors of musculoskeletal disorders. The objective of this study was to document workplace and symptom changes 1-2 years after the initial assessment. Initially, worker injuries and symptoms, work tasks, tools and equipment were documented. In addition, an ergonomic assessment was completed and recommendations for workplace interventions were provided. After comparing the job requirements and worker abilities, gaps between the two were identified. Recommendations were then developed to eliminate the gaps so the worker could perform the job.

## METHOD

During the initial visit to the work site, workplace documentation was collected. The documentation included worker injury and symptom history, sketch of the work area, description of the work objective, tasks, work equipment, tools, materials, environment, and work schedule. In addition, real-time and time lapse (only a subset of workers) videotape of the worker performing the job was taken.

Next an ergonomic assessment of the risk factors related to musculoskeletal disorders was completed using a methodology developed by Latko, et al. (1). 10-point scales were used to rate the risk factors where 0 = very low level of exposure and 10 = very high exposure. The ergonomic risk factors that were rated included repetition, force, posture and localized contact stress. After review of the ergonomic assessment, intervention recommendations were developed to address the identified risk factors. Implementation of the workplace changes were the responsibility of the employer and were made in consultation with the worker and/or worker representatives.

Twenty-four workers were contacted for a telephone follow-up interview 1-2 years after the initial assessment. Twenty-two workers representing thirteen unique jobs completed the telephone interview (19 female, 3 male; age=43±9.98 years). The telephone interview collected basic job information, descriptions of implemented interventions, and current symptoms. Five jobs were evaluated again after the workplace changes were implemented.

## RESULTS AND DISCUSSION

Table 1 contains a list of the work place changes for the various workers who participated in this study. Implemented interventions included keyboard trays, sit-stand workstations, document holders, carts, job changes and many others. The total number of interventions implemented was 99 and the average number of interventions implemented per worker was 4.7± 2.4 (minimum = 0, maximum = 8).

Initial worker symptoms and diagnoses included carpal tunnel syndrome, epicondylitis, non-specific arm, shoulder, neck, back and knee pain. At follow-up, symptoms had decreased for 12 workers, increased for 3 workers and were the same for 7 workers.

Table 1: Implemented work place changes for each job.

| Case | Job Title | Work Place Changes |
|---|---|---|
| A | Accounts Payable Coordinator | Monitor and keyboard placed directly in front of worker, document holder, wrist rest, sit upright while writing, adjustable chair, newer & faster computer, eliminated filing. |
| B | Special Education Teacher | Moves her chair around the room when she is working with students rather than bend forward. |
| C | Engineering Advisor | Adjustable monitor arm, adjustable keyboard tray, sit/stand workstation, adjustable chair. |
| D | Copy Editors (5) | Use carts to transport heavy journal boxes, position computer monitors in front of worker, monitor stands, document holders, slant board for reading and writing (one worker). |
| E | Technical Typists (3) | Document holder next to monitor. |
| F | Computer System Administrator | New job: half-time Database Manager. Centering the monitor in front of worker, wrist rest, chair arm supports, using elevator instead of stairs, half-time schedule. |
| G | Quality Control | None. Same job and going to school. |
| H | Customer Service Representative (4) | Adjustable chairs with armrests, keyboard trays, roller-ball mouse. |
| I | Medical Secretary | Job change (still Medical Secretary). Chair with armrests, flat screen monitor, adjustable keyboard tray, wrist rest, used left hand for mouse until right arm pain decreased, document holder. No longer transports x-rays. |
| J | Academic Secretary | Adjustable height and tilt desk, chair arm rests used when mousing, adjustable keyboard tray, trackball, Microsoft natural keyboard, used left hand for mouse until her right arm pain decreased. |
| K | Senior Health Record Analyst | Touch pad mouse, mouse with left hand, Microsoft natural keyboard, adjustable keyboard tray, side tables as writing areas, footrest, adjustable chair with arm rests. |
| L | Senior Health Record Analyst | New keyboard, touch pad mouse, moved phone closer to her, chart holder. New job: Medical Coding Specialist – less time on the computer, sit/stand (spends a lot of time at the nurses station on the floor), smaller charts. |
| M | Supervisor, Marketing Communications | Macally *ikey* keyboard (standard shaped Macintosh keyboard with a curved space bar), adjustable keyboard tray, wrist rest, stylus on a touch pad instead of a mouse, adjustable tray for touch pad, monitor stand. |

Ergonomic evaluations of 5 jobs were completed when the follow-up interviews were conducted. Table 2 contains a summary of the changes in the symptoms and ergonomic risk factors for these jobs. Reported musculoskeletal symptoms decreased for 3 of the workers, increased for one worker and stayed the same for one worker. The peak forceful exertions associated with all jobs decreased. However, there were both increases and decreases in hand activity level (repetition) and posture stresses. Overall, the changes in contact stress were minor. For the worker whose symptoms increased, the academic secretary, changes in the computer program she regularly uses occurred right after the interventions were implemented. The new software is mouse driven and she must now spend considerably more time using the computer. It was her opinion that there had not been enough time for her to heal after the interventions were implemented before the job changes occurred.

Table 2: Changes in ergonomic risk factors and symptoms after interventions were implemented.

| | Medical Secretary | Academic Secretary | Senior Health Record Analyst | Senior Health Record Analyst | Supervisor, Marketing Communications |
|---|---|---|---|---|---|
| Symptoms | ↓ | ↑ | = | ↓ | ↓ |
| Hand Activity Level | = | ↓ | ↑ | ↑ | = |
| Force | ↓ | ↓ | ↓ | ↓ | ↓ |
| Contact Stress | Minor changes. Hard plastic armrest on chair | Minor changes. Hard plastic armrest on chair | Slight increase due to resting forearm and elbow on table edge. | Increased finger contact stress due to hand writing. | Decreased due to rounded desk edge and padded arm rests. |
| Posture Stress | Minor changes. Medium radial / ulnar wrist deviation. | Decreased shoulder, neck and back posture stress. | Increased peak posture stress for shoulder, neck and back to reach for charts and phone, and read materials. | Minor changes. Shoulder posture stress to reach for code book and flip through notebook and back twisting to reach code book. | High peak shoulder posture stress to reach for phone and high peak neck posture stress when cradling phone. |

Various strategies to reduce the incidence and symptoms of musculoskeletal disorders in the workplace are often used. Because many work and personal factors contribute to the development of musculoskeletal disorders, symptoms are often difficult to resolve. After the implementation of workplace interventions based on ergonomic analyses, discomfort was reduced for most of the workers in this study. However, due to other work place changes symptoms did not resolve for all workers. Management of musculoskeletal disorders includes both a medical and work place component and continued follow-up and re-evaluation are necessary to identify and re-fine appropriate work place ergonomic interventions.

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# AN ASSESSMENT TOOL FOR ENVIRONMENTAL CONTROL PROVISION

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## ABSTRACT

Environmental Control Systems (ECS) help people with a severe physical disability to maintain or increase independence by giving them a means to operate electrical appliances from a central control (Medical Devices Agency 1995). This paper introduces the use of a 'temporary installation' for those clients with severe cognitive difficulties who present a challenging assessment or those with rapidly deteriorating conditions. Results confirm a significant cost saving for the health service providing the equipment and a substantial time saving for the clients. They also confirm that the units help to improve the user's self-esteem, improve their independence and reduce their dependence on carers.

## BACKGROUND

The first ECS was produced in the late 1950s for survivors of the polio epidemic (Dicey R et al 1987 cited in Wellings and Unsworth 1997). Over the next 30 years improvements were made in the design and range of appliances that could be operated via the ECS but they remained cumbersome. Advances in technology have since led to more sophisticated systems, which now have the potential to operate communication aids, computers and wheelchairs as well as household equipment. Many ECSs incorporate a remote unit which is unobtrusive and easy to mount on wheelchairs. These units may now have up to 1000 functions and switch input can now be individually designed for and by the user. Larger display units are available for those people with visual impairment and those with learning or cognitive problems who benefit from icons rather than words and an auditory feedback to operate the system.

An environmental control system consists of 3 main elements:

1) The user interface (Input switch to access the system). This may be operated by hand, foot, and chin, to the extreme of eye blink or suck/puff or may be voice activated.
2) The system (A controller). This learns and stores the codes needed to control the household appliances and usually present as a simple scanning menu format. They may transmit in Infra Red and/or Radio.
3) The environment (Accessories). These are the appliances operated by the controller. The most commonly used devices are hands-free telephones, intercoms, door openers, televisions, satellite and Hi-Fi systems.

In the UK, ECS are prescribed free of charge by the National Health Service (NHS) following a clinical and independence needs assessment (BSRM 2000).

There are currently three suppliers of Environmental Control Equipment on the NHS contract, the companies involved agree to have their equipment evaluated by a third party, PASA, and if agreed, they are then placed on contract with the NHS. Not being placed on contract does not exclude other companies from offering their services under the European directive, but purchasers tend to only obtain equipment that has been placed on contract.

## STATEMENT OF THE PROBLEM

Although EC systems are offered to those of any disability and of any age, the assessors or therapist involved in the service are under pressure when providing expensive equipment to those with severe cognitive disabilities or those with rapidly deteriorating conditions. In the past, this may result in either the patient not being provided with equipment or the service funding equipment that may not be used effectively. The aim of this project was to incorporate the use of temporary installation kits, 'Techno trolleys' into the Environmental Control prescription process and to establish the true need of the client without the draw on the installation budget.

## METHOD AND APPROACH

The Techno trolleys allow for existing equipment to be used for extended assessment trials and as an interim measure for rapidly deteriorating cases while awaiting the full installation of equipment from the suppliers. This also permits a developmental approach whereby the complexity of the system can be increased as the user develops their confidence and capabilities.
The idea of the Techno Trolley originated from the hospital based Regional Rehabilitation Unit (Professor Lynne Turner Stokes) at Northwick Park Hospital, England whereby a 'trolley' consisting of one EC unit, a switch input matched to the users needs and various appliances including a television, lamp and fan, would be wheeled to the patient's hospital bedside.
For the home environment, it was determined that a better response was found if the users own appliances were programmed into the EC unit. It has therefore now developed that the unit is customised for the individual with the Rehabilitation Engineer programming the unit on site.
Those clients who are provided with a Techno Trolley to establish motivation and cognitive ability, find a voice-prompted system easier to understand. The Freeway also allows for the complexity of a system to be dramatically reduced to as little as one function and therefore, in general, if the user is unable to use this unit, they are unlikely to be suitable for an EC system.

## PRESCRIPTION

The flow chart shown in Fig. 1 shows the procedure necessary for prescription of a Techno Trolley Environmental Control System:

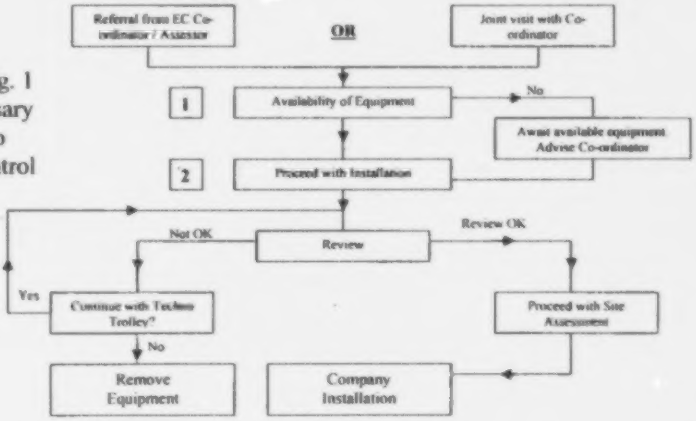
Referral from EC Co-ordinator / Assessor
OR
Joint visit with Co-ordinator
1
Availability of Equipment
No
Await available equipment Advise Co-ordinator
2
Proceed with Installation
Review OK
Not OK
Review
Yes
Continue with Techno Trolley?
Proceed with Site Assessment
No
Remove Equipment
Company Installation

Fig 1

At point 1, the availability of the EC Equipment, the mounting kits and available switches would be determined.
At point 2, the EC Co-ordinator will be asked to attend if there is a problem with determining a switch or an issue with posture. We will also invite a representative from Social Services to the

installation. At this stage this would be for their information only but if the client goes on to have a full company installation, input and funding from Social Services will be required. Following installation, a review will take place after approximately 8 weeks.

## RESULTS

The results shown are following a caseload of 24 past and present users of Techno Trolleys. Following the initial assessment, the main reasons why an assessor would refer for a Techno Trolley can be established and grouped together to form a percentage: One client may come under more than one category.

| | |
|---|---|
| 32% | Unsure as to the extent of understanding of Environmental Control Principles |
| 30% | To determine the motivation of using an ECS |
| 15% | Due to a deteriorating condition |
| 15% | To identify suitable switch access |
| 5% | To identify a scanning method |
| 3% | Other |

Out of these 24 users:

| | |
|---|---|
| 14 | System have been withdrawn due to lack of motivation or cognitive difficulties |
| 5 | Are ongoing with the trial with the outcome still to be determined |
| 1 | New referral, waiting to be seen |

Only 4 users (16%) have gone on to have a referral for a full company installation.

## DISCUSSION

The current results have shown a low proportion of Techno Trolley provision going on to be referred for a full company installation, emphasising the overall cost saving for the service in unnecessary installations. This also results in more appropriate prescription and thus higher use. Future development includes the integration of other Assistive Technology including wheelchair control and communication aid integration.

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# MEASURING THE COST UTILITY OF ELECTRONIC AIDS TO DAILY LIVING

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## ABSTRACT

Studies demonstrate that electronic aids to daily living (EADLs) improve autonomy, self-esteem and quality of life for persons with severe physical disabilities. However, this technology is not easy to obtain due to lack of funding by third party payers. We have assembled a protocol of outcome measures to examine the cost utility of this technology. In this study, we are evaluating the reliability and validity of these measures. If we find that they are reliable and valid, we will use the data to examine the cost utility of EADLs, comparing the experiences of users with nonusers. The results of this and other research may help to influence the funding policies of third party payers.

In this paper we share: a) the approach to cost utility analysis that we are testing; b) the rationale for including the content that we have in our protocol; and c) opportunities for research collaboration and future study.

## BACKGROUND

Electronic aids to daily living (EADLs), also known as environmental control devices, foster personal autonomy as they can enable persons with severe physical disabilities to use many household devices such as telephones, door openers, and stereo systems through alternative access methods. EADL users report that a major benefit of using EADLs is increased independence, functional competency, and personal control to engage in leisure and vocational activities of their choice (1, 2, 3). Users inform us that the increased autonomy, in turn, enhances their self-worth, self-confidence and quality of life (QoL) (1, 4).

Despite a growing body of evidence about the benefits of EADLs, this technology is not widely used (5). The high costs for EADLs and the lack of third party reimbursement are cited as the major obstacles preventing prescription of this technology (5). Cost utility analysis of the impact of EADLs for persons with severe physical disabilities is critical to policy development concerning the funding of EADL technology, service delivery and training (6). Cost utility analysis has rarely been done in rehabilitation and for assistive technology. Consequently, there are few tools available to do such research. We reviewed the recommendations arising from the study conducted by The Commission of the European Community (EC), *Cost-Effective Rehabilitation Technology through Appropriate Indicators (CERTAIN)* (7). The impetus for the CERTAIN study was the need to demonstrate cost-effectiveness of assistive technologies (AT), in light of resource constraints and growing costs, choices, and advances in technology. They developed the CERTAIN tool which evaluates AT user goals, expectations, satisfaction QoL. It is based on the preferences of users for various outcomes (i.e., outcomes are specific to each user).

The main obstacle, which has prevented us from adopting the CERTAIN tool for cost utility analysis of EADLs, is that it is administered with AT users before and after provision of the technology. We do not feel that this approach is feasible for the study of EADLs. This technology is seldom prescribed due to limited funding options, consequently it would take a long time to recruit an adequate sample of new EADL users for a prospective, outcomes study. This became apparent during one of our studies, in which we had intended to enroll 20 new users over a 2-year period from a community of about 3 million people. There were only 8 new EADL users who fit our inclusion criteria during that time (3). In view of this, we felt that we needed a tool that could compare the experiences of EADL users with nonusers. Another problem that we encountered in our previous studies was finding appropriate evaluation tools. We tried two AT outcome measures that evaluate satisfaction with and psychosocial impact of the technology (2, 8), but found that they were not suitable for comparing experiences of nonusers with users of this technology. For a cost utility analysis, it is critical to compare monetary, functional and QoL variables between those who are using the technology and those who are not using the technology (9).

We have developed a prototype of a cost utility protocol that retains similar features of the CERTAIN tool, and in addition, can compare the experiences of EADL users with nonusers as well as the experiences of users before and after provision of EADLs. The individual tools included in this protocol would also be useful for outcome evaluation of rehabilitation services using EADLs.

## OBJECTIVE

The main purpose of this project is to evaluate a protocol to measure the costs and consequences associated with using EADLs. Costs are typically viewed as the monetary resources used to produce an outcome, while consequences can include the functional, psychosocial and monetary outcomes of applying a particular intervention (9). We plan to evaluate the internal consistency, the test-retest reliability and inter-rater reliability of tools that we developed for this protocol. A secondary goal for this project is to use the data for an analysis of the cost-utility of EADLs, if we find that the tools are reliable and valid. In this presentation we will share: a) the approach to cost utility analysis that we are testing; b) the rationale for including the content that we have in our protocol; c) the preliminary results from this study; and d) opportunities for research collaboration and future study.

## METHOD

We propose that the evaluation of the costs and consequences associated with EADLs should include the following content about the EADL user and the potential user (i.e., the nonuser): type and frequency of daily occupations (including vocational and leisure pursuits); frequency and intensity of care received; household income; ability and satisfaction with doing daily tasks that can be enabled with an EADL (e.g., entering and exiting their home, using their phone); interpersonal relationships; safety, security, and QoL. We established the content validity of the protocol from several sources including: thematic analysis of qualitative data obtained through semi-structured interviews with EADL users and nonusers, focus groups with key informants, results from our previous studies, and critical review of the literature.

Our protocol is comprised of six questionnaires: two with established reliability and validity, four other measures we revised or developed for this research project. The established measures include the Functional Independence Measure (FIM) (9) and the Quality of Life (QoL) Profile: Physical Disabilities (short version) (10). The remaining four questionnaires include: a revised version of The Lincoln Outcome Measure for Environmental Controls (11), the Personal Profile, the

Caregiver Questionnaire, and the Daily Life Satisfaction Scale. We are testing the reliability and validity of the latter four measures as part of this project.

In this study, we are including persons with quadriplegia due to spinal cord injury or disease. We will compare the experiences of a group of 18 EADL users with a group of 18 nonusers who have a comparable level of functional independence as measured on the FIM. Each participant will be interviewed twice (for test-retest reliability) in their home by an occupational therapist familiar with the tools and with AT's. We are also interviewing their principal caregiver.

## DISCUSSION

Upon completion of this study, we will have refined and focused the content for this protocol, plus we will have greater knowledge of the reliability and validity of the individual tools. During this presentation we will provide preliminary results of this study, including analysis of the cost-utility of EADLs for this sample. In future, we wish to collaborate with others to examine the cost utility of EADLs for other populations who use or could benefit from this technology. This, in turn, may influence funding policy for EADLs.

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# UNIVERSAL DESIGN EXEMPLARS

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## ABSTRACT

Broadcasting examples of universal design is critically important, not just for its timeliness to further the understanding, promotion and adoption of universal design, but also for its intended audiences—the designers and users of spaces, buildings, information and products. This session will display contents of acclaimed new CD of Universal Design Exemplars in the fields of Architecture, Exhibit Design, Industrial Design, Interior Design, and Landscape Architecture.

## BACKGROUND

Visual documentation of universal design is critically important, not just for its timeliness to further the understanding, promotion and adoption of universal design, but also for its intended audiences–the designers and consumers of spaces, buildings, information and products all of us will be using as we enter the 21st century.

In August 1998, The Center for Universal Design was awarded grants from the National Endowment for the Arts and NEC Foundation of America to develop a CD-ROM collection of Universal Design Exemplars. Subsequent funding was obtained from the Trace R&D Center at the University of Wisconsin-Madison under its RERC grant from the National Institute on Disability and Rehabilitation Research. This project builds on the successful Images of Excellence project conducted by Universal Designers and Consultants, the National Endowment for the Arts and the National Building Museum in 1996.

The purpose of these exemplars is to identify, describe and visually document excellent examples of universal design from across the design disciplines including architecture, landscape architecture, industrial design, interior design and exhibit design.

## RESEARCH QUESTION

Universal design exemplars are an effective instructional and learning tool to further promote the understanding and implementation of universal design principles. The interactive nature of CD ROM enables the user to explore the selected projects in-depth through accompanying images and text, and to cross reference projects by design discipline and the project's relationship to one or more of the Principles of Universal Design. Project examples include multiple images that show the object or space in use or in the context for which it was designed, and highlight various features that make the project universal. Drawings and illustrations are used to further enhance the projects.

## METHOD

A Call for Entries was announced in the winter of 1998. The Center broadly advertised the project through professional journals, Web sites and listservs, direct mail to professional associations and design schools, and articles in various magazines and newsletters. Eighty-five entries from across the design disciplines were received from around the world. Submitted projects included homes and interiors; public facilities such as an artist colony, playgrounds, and gardens; consumer products including cookware, lamps, and chairs; and information systems such as a zoo map and museum displays. A panel of nine expert jurors reviewed all the entries and helped recommend the final 40 projects selected for the CD ROM.

## RESULTS

At the time of this presentation, the Center will have been distributing the CD ROM for over one year. The CD is made available through the Center, as well as other distribution channels. In addition, much of the information is available on the Internet on the Center's Web site. It is critically important that new audiences experience the breadth and depth of the examples on the CD.

Primary audiences for the CD ROM include students and faculty in schools of design, as well as design professionals. Other audiences include public, private and non-profit leaders who influence or commission design development and production. For example, federal agencies who support universal design research, education or technical assistance, as well as disability organizations who want to influence the design and production of new spaces, public facilities, or consumer products. A goal of the project is to also provide the CD ROM to high school students who may be considering design careers.

## DISCUSSION

Universal usability is a goal. As such, designers strive to create products and environments to achieve that goal. Few, if any projects, achieve 100 percent universal usability. Based upon the reviewers' comments and the entry forms provided by each submitter, the panel selected the Principles of Universal Design that each project most typified; there may be aspects of other Principles that the project incorporates. The goal was to help the viewer understand the distinctions between the Principles and to see them applied in real world projects.

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The Center for Universal Design, with support from the National Endowment for the Arts (NEA) and NEC Foundation of America, developed the CD ROM collection of Universal Design Exemplars.

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# FUTURE HOUSING NOW: THE NEXT GENERATION UNIVERSAL HOME

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## ABSTRACT

The *Next Generation Universal Home* is a conceptualization of how housing may evolve over the next fifteen to twenty years in response to present and future demographic and marketing trends. The concepts and solutions it presents are based on existing technologies and coincide with popular design approaches. As such, the Next Generation Universal Home's innovation is not based on manufacturing or technological advances, but rather on a change in thinking about how people actually live in their homes. This approach is called universal design and this paper lays out the need, range of solutions, and possible future of the concept when applied to housing.

## BACKGROUND

It has been nearly two decades since Ron Mace coined the term "universal design," yet we are just beginning to see the emergence of this concept in the mainstream housing market. Several high profile projects of recent years have brought visibility to the movement. These include Lifestages 99, an innovative modular home design which was the central floor exhibit at the 1999 International Home Builders Conference (1), Better Homes and Garden's Blueprint 2000 House (2), and the Universal Design House sponsored by the American Association of Retired Persons (3). These projects have ranged from just the inclusion of prominent universal features to true holistic universal designs. In a landmark publication, in 2000, Home Planners, LLC, a Division of Hanley-Wood, Inc., published the first book of universal home plans, called *Products and Plans for Universal Homes* (4), which has been widely distributed across the country.

Among these precedent-setting projects is the *Next Generation Universal Home*. This project, one of the last that Ron Mace worked on, represents the collective experience of the staff of the Center for Universal Design and identifies specific features and design elements that can be incorporated into every home.

The Next Generation Universal Home was developed in response to a request from editors of the Wall Street Journal for information for a feature they were planning about future housing trends for the retiree market. Their intent was to define and describe "the house of the future." Center staff used the term "next generation," stressing what is possible today and what will become feasible in the near term. The Center developed an original illustration of a theoretical home design that was published in the Wall Street Journal (5).

## STATEMENT OF THE PROBLEM

The primary goal in developing this home design was to raise awareness of what is possible by presenting universal design in housing in a comprehensive and holistic way. The idea was to design and promote living spaces designed not for specific users, but for everyone.

## RATIONALE

Single-family houses in the United States today are built much as they were 50 years ago, with the exception of improved technology in elements such as better insulating windows and various electronic control devices. However, the housing industry must adapt to the growing diversity in family types in the U.S. In 1972, the most common type of household, i.e., 45 percent, consisted of married couples with children. But by 1998, the number had dropped to 26 percent, a dramatic shift from a generation earlier. And the population is aging. By 2030, there will be close to 70 million older adults in the U.S., more than twice the number in 1996 (6).

A growing community of designers, researchers, and educators worldwide is recognizing that the built environment cannot be designed for one specific population, but rather it should work for a dynamic range of people and abilities. In addition to being environmentally sensitive and sustainable, housing of the future must possess an ability to adapt to the differing needs and requirements of users, no matter their age or strength or agility. This design approach, known as universal design, strives to make practical day-to-day tasks possible and safer for everyone.

## DESIGN

The basic structure of the Next Generation Universal Home is based on typical American house designs currently being constructed. Moderate to upper-end suburban house styles were used as models to demonstrate that universal concepts can be thoroughly effective in common popular home styles and do not require unconventional or "space age" approaches.

The floor plan demonstrates careful space planning and fixture placement combined with necessary maneuvering clearances. While easy to implement, the home's unusual features such as level entrances and reinforced bathroom walls for grab bars run counter to traditional construction methods. The home layout reflects some recent trends in house design that are likely to continue. Many of these are conducive to and supported by universal design concepts, most notably the use of open or flexible-use spaces. An additional first floor bedroom can be designed to accommodate guests or a home office. A second master bedroom and bath can be used as a suite for care of an elderly parent or relative if needed. Compartmentalized baths can be used by more than one person. Other popular spaces such a mud room, a shared bathroom, spacious master baths and walk-in closets, and a computer niche have been included, too.

Deliberate and careful attention was paid to details to ensure that this theoretical design incorporates the full intent of universal design. However, all universal features are not discussed here, as the focus is on the critical conceptual approaches. Other features and details not included would also be effective. For a more exhaustive listing of universal features for housing developed by the Center for Universal Design, see Ron Mace's 1998 article in *Assistive Technology* (7).

## EVALUATION

Approximately 1000 posters of the Next Generation Universal Home have been distributed and have been well received as an educational and awareness piece. It communicates effectively to both consumer and professional audiences through its three dimensional but simple appearance. Some architects have criticized the home design as being too generic and not sufficiently stylish, but the designers did this intentionally in order to communicate more effectively with builders and developers who produce the majority of housing in the U.S. Since its debut, numerous newspaper and magazine publications have requested to reprint the illustration.

## DISCUSSION

In comparison to most of the fixed features of the past, this design relies on adjustably to accommodate the widest range of users. Height-adjustable counter tops are used in the kitchen and bathrooms. Rotating and height-adjustable shelves maximize storage. Toilets have height-adjustable seats. Bathing spaces allow more than one method of use – standing, seating, or reclining – particularly in the multi-mode bathing fixture previously developed by the authors. All of the illustrated features are technically possible now, although some are not widely available. For example, a limited selection of height-adjustable counter tops and rotating shelves are available, while other features such as the multi-mode bathing fixture are not currently manufactured.

One unexpected element of the Next Generation Universal Home is that it has two stories. This may run counter to many people's notion of what constitutes a universally designed home. However, the designers included this feature because of the prevalence of two-story homes and the likelihood that developers will continue building them. The design does provide several strategies to resolve the use of the second story. In addition to the other major living spaces on the first floor, a full bedroom and bathroom are included for someone who has difficulty with stairs. Stair design is critical to whether a platform lift can be installed. The stairway design used in the home accommodates either a chair or platform lift. The stairway width is increased and additional space is provided at the top and bottom of the landing to disembark from and to store a lift. Finally, the house contains a storage closet on the upper floor that is located above a matching one on the lower floor, so that the flooring between them can be removed to create an elevator shaft if needed. The elevator solution, while potentially more expensive, is integral to the house and less obtrusive than a stair lift.

The Next Generation Universal Home and the home designs of others described above reflect the increasing sophistication and application of universal design in single-family home construction. The next century promises new innovations in housing resulting from advances in computer technology, manufacturing processes, materials applications, and areas yet undiscovered. If these are approached in a thoughtful way with a commitment to the end user, more effective solutions than the ones existing now can be implemented. Ideally, the next generation of housing will be more inclusive and contribute to a built environment that is a more universally usable one.

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# AN INRFRARED ELEVATOR CONTROL SYSTEM

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## ABSTRACT

Most public buildings are required to be wheelchair accessible via items such as ramps and automatic doors. Although these items assist someone in accessing the first floor, they do little to assist a person in a wheelchair trying to access another floor. An elevator panel has been modified by implementing an infrared (IR) receiver that allows a person in a wheelchair to operate the elevator panel from his/her wheelchair. The standard 12-button keypad used as input for the transmitter places the buttons of the elevator panel at the fingertips of a people in wheelchairs, making it easier for them to use the elevator.

## BACKGROUND

State and federal regulations require that most buildings be accessible to handicapped persons by means of ramps, automatic doors, etc. All of these aids help a handicapped person access the first floor of a building, they do little to assist someone with limited hand/arm movement access other floors. Although elevators are installed in most of these buildings, they are often difficult or impossible to use for someone in a wheelchair with limited use of his/her arms or hands.

## STATEMENT OF PROBLEM

The goal of this project was to design an IR transmitter/receiver that will allow a disabled person in a wheelchair to more easily use an elevator. The transmitter is small, inexpensive and consumes minimal power since it runs a 9V battery. The receiver has an output identical to that of the existing elevator panel so that its output can be directly combined with the existing elevator panel.

## DESIGN

*Infrared Transmitter*. A block diagram of the IR transmitter can be seen in Figure 1. The IR transmitter was designed around the Holtek HT-12A encoder IC.

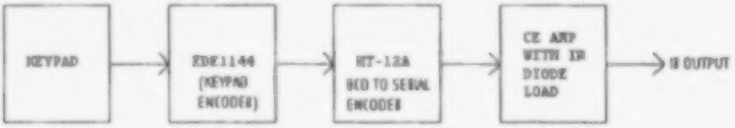

**Figure 1: IR TRANSMITTER BLOCK DIAGRAM**

The input to the system is obtained from a 3x4 keypad in conjunction with an EDE1144 keypad encoder IC. The EDE1144 allows the keypad data to be decoded to a more useful form, in this case serial and four-bit BCD. The four-bit BCD outputs from the EDE1144 are fed to the HT-12A's data inputs. The HT-12A has an output enable feature that only enables the output if one of the data inputs is low. The EDE1144 allows us to use this feature since it outputs <1111> when no button is being pressed on the keypad. The HT-12A also has eight address bits that can be set high or low. The purpose of these address bits will be explained in more detail later. The HT-12A outputs serial data consisting of 13 pulses. An example of this data can be seen in Figure 2 for BCD input <0111>.

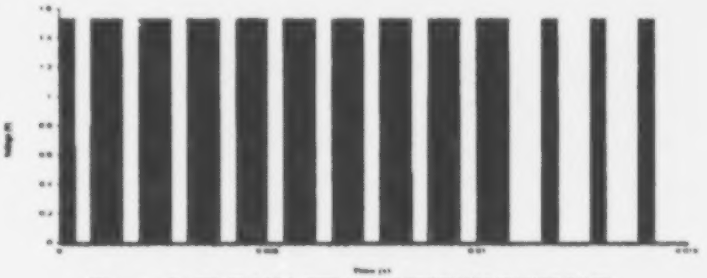

Figure 2: IR DATA TRANSMISSON FORMAT

The first pulse declares the beginning of a word, the next eight pulses represent the eight address bits and the last four pulses represent the four data bits. The pulses are width modulated, meaning a pulse is wide when the corresponding bit is low, and a pulse is narrow when the corresponding bit is high. This data is fed to a common emitter amplifier using an IR emitting diode as a load. The transistor used is a ZTX603 high performance Darlington NPN transistor, giving a large current gain to the signal. The amplifier functions such that when there is no base current, meaning the signal is low, there is no current flowing through the IR diode, and thus no signal is transmitted. When there is base current, meaning the signal is high, base current is amplified and pulled through the IR diode in turn emitting a strong IR signal. A small resistor is placed in series with the IR transmitting diode to limit the current and avoid burning out the diode.

The transmitter consists of 2 IC's, a keypad, a transistor, an IR emitting diode and around a dozen resistors. This is fairly inexpensive and will fit onto a small circuit board that can fit into the hand of a client or be mounted on the arm of a wheelchair.

*Infrared Receiver*. A simplified schematic of the IR receiver can be seen in Figure 2. The receiver was designed around the Holtek HT-12D decoder IC, which is made to function with the HT-12A.

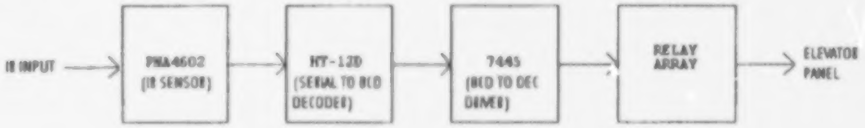

Figure 3: IR RECEIVER BLOCK DIAGRAM

A PNA4602 IR detection module picks up the IR signal emitted via the transmitter. This module accepts only data modulated near the 38kHz region, blocking interference from other signals that may be around. The signal is also amplified by the PNA4602 to a level that can be used to drive the input of the HT-12D. The HT-12D in turn takes the serial input and restores the original four-bit BCD data. The HT-12D, like the HT-12A, has 8 address pins. These pins must be set to the same sequence as the HT-12A in order for the data to be decoded. A 7445 BCD to DEC driver then further decodes this data back to its decimal form. Each of the 7445s outputs is used to

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drive an electronic relay switch. These switches are placed in parallel with the existing switches on the elevator panel.

## DISCUSSION

This product has the potential to improve access to buildings for people in wheelchairs with and without limited use of their hands or arms. This system could be applied in many situations to help handicapped people use elevators. It could for instance be implemented in an apartment building to help someone in a wheelchair get in and out of the building. It could also be implemented in office buildings and transmitters could be issued to visitors and workers.

This project has demonstrated how IR technology can be used to assist handicapped people. This technology could be implemented to help handicapped people with other tasks. For instance, it could be implemented on a crosswalk switch, allowing easy use by someone in a wheelchair.

## ACKNOWLEDGEMENT

This project was developed with the support of the Electrical Engineering Department at the University of Massachusetts Lowell and funded by the National Science Foundation. The author would like to acknowledge the support of Prof. Donn Clark and Prof Alan Rux who run the Assistive Technology program at the University of Massachusetts Lowell.

# ENHANCED QUALITY OF LIFE THROUGH THE APPLICATION OF UNIVERSAL DESIGN PRINCIPLES TO OUTDOOR RECREATION OPPORTUNITIES

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## ABSTRACT

Rehabilitation aims to create a higher quality of life and research indicates that leisure satisfaction is the key factor in the quality of life for people with disabilities. Outdoor recreation opportunities are the most popular forms of leisure. The Universal Trail Assessment Process (UTAP) applies the philosophy of universal design to the development of outdoor recreation opportunities. Through the UTAP, universal design can be applied to outdoor, natural environments to meet the needs of all potential users through the identification and removal of barriers, matching trail design with user and environmental protection needs, and enhancing user safety and enjoyment through the dissemination of accurate information.

## STATEMENT OF PROBLEM

Awareness of the importance of recreation for people with disabilities has increased since the Americans with Disabilities Act (1990) established a legal mandate for access to recreation facilities and services. Recent health research policy initiatives have focused on the importance of recreation and physical activity for people with disabilities (1) in response to research linking exercise participation and satisfaction with leisure among people with disabilities to overall quality of life (2). Kinney & Coyle (2) found that leisure satisfaction explained 42% of the variance in overall life satisfaction, a proportion much higher than that attributed to financial status, self-esteem, health satisfaction, religious satisfaction, and marital status (11%).

Traditionally, society has focused primarily on the medical needs of people with disabilities, with a much lower emphasis on well-being and quality of life (1). In relation to outdoor recreation opportunities, misperceptions about what is required in order to create an "accessible environment" have compounded the perceived lack of priority for recreation in general. People with disabilities, themselves, do not focus on the need for asphalt or concrete trail surfaces. Rather, they have identified the major access barrier in outdoor, natural environments as a lack of objective, reliable information (3).

Our society has also shown an increasing interest in environmental preservation (4) and outdoor recreation opportunities in recent years. Major federal land management agencies, such as the USDA Forest Service, report a steady increase in the number of visitors each year (5) and outdoor pursuits make up 50% of the most popular recreational activities (6). The combination of a legal mandate for access to recreation facilities and services, recognition of the importance of recreation for people with disabilities and an increasing interest in outdoor recreation opportunities have generated a tremendous need to provide land managers with guidance on the most effective ways to balance the need for accessibility with environmental protection.

## APPROACH

The Universal Trail Assessment Process (UTAP) was developed in recognition of the need for objective, standardized information about the conditions in outdoor, natural environments. It recognizes that enhancing access to a natural environment is self-defeating if the "natural" components of the environment are substantially altered. It also recognizes that access does not require level, paved surfaces but rather an accurate understanding of the conditions to be encountered. The UTAP (3) objectively measures path grade, cross slope, surface, and width as well as the size and frequency of obstructions. Typical values for each of these variables, as well as descriptions of extreme conditions, are summarized as Trail Access Information. Research to develop the UTAP established its validity and reliability. Use of the UTAP is increasing and is expected to expand rapidly once the ADA Accessibility Guidelines contain specific requirements for accessible trails. Current efforts are focused on developing a training program to enhance the national pool of trainers who can teach the UTAP training workshops.

## DISCUSSION

The seven principles of universal design are equitable use, flexible use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use. The UTAP is a structure for applying these principles to outdoor, natural environments (3). UTAP was designed for equitable use because it generates information for all potential users, not only those with disabilities. Flexible use is reflected in its suitability for all outdoor environments and a variety of measurement needs, such as mapping, maintenance, environmental protection and accessibility. Research indicating that the UTAP can be accurately implemented by young teenagers to older adults, under skilled supervision and with less than 30 minutes of training, indicates that it is simple and intuitive to use. The UTAP collects objective information about the perceived conditions of the environment and conveys that information to users in a variety of accessible formats. Research has also established its tolerance for error in that differences in measurement location do not significantly influence the overall results. The physical effort and space required to implement the UTAP are limited only by the conditions of the natural environment.

Three case studies demonstrate the application of the UTAP by land managers to a broad range of goals. California State Parks has applied universal design principles to the redesign of an existing trail in North Coast Redwoods State Park. The UTAP was part of a systematic process to identify and achieve the maximum level of access without compromising the natural or cultural resources of the park. By assessing the existing conditions, and focusing on meeting the needs of all potential users, accessibility to the trail was significantly enhanced. Minnesota Department of Natural Resources and Wilderness Inquiry have completed assessments in all Minnesota state parks using the UTAP. The information collected there was used to identify access barriers for subsequent remediation and to disseminate information about the actual conditions that would be encountered to all potential users. Indiana Department of Natural Resources has focused on enabling informed choice among trail users by providing access to the results of the UTAP in its state parks through the Trail Explorer web site.

## CONCLUSIONS

The UTAP demonstrates that the principles of universal design can be effectively applied to the creation of accessible outdoor, natural environments. It provides a specific format that enables land managers, conservationists and people with disabilities to actively support outdoor recreation access through a universal design approach. This type of approach to accessibility provides many benefits, such as minimizing environmental impacts and access barriers, enhancing user safety and satisfaction, and empowering people with disabilities to choose the outdoor recreation activities they would enjoy. Increased training of UTAP workshop leaders and an education process for users and land managers will make the benefits of universal design for outdoor, natural environments more widely known and available. Widespread implementation of universal design in outdoor environments will significantly enhance the quality of life of people with disabilities.

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# Functional Control and Assistance
## (Topic 5)

# THE DESIGN AND KINEMATIC EVALUATION OF A PASSIVE WEARABLE UPPER EXTREMITY ORTHOSIS

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## ABSTRACT

A passive, wearable, upper extremity orthosis with the potential for four powered degrees of freedom was designed and evaluated. The design provides shoulder flexion and abduction, humeral rotation and elbow flexion. The kinematic performance of the orthosis was evaluated by simulating 8 activities of daily living involving reaching, manipulating objects, feeding and grooming. The results indicated that a powered orthosis based upon this design could have wide application.

## BACKGROUND

Duchenne muscular dystrophy (DMD) is characterized by a progressive proximal to distal degeneration of skeletal muscle groups. As the disease progresses, individuals are confined to a wheelchair and the upper body experiences progressive muscular deterioration from the shoulder toward the hand. Although these individuals generally retain dexterity in the hand throughout their teenage years, they lack sufficient arm strength to position the hand so as to perform many daily living functions. Mobile arms supports, wheelchair mounted orthoses and robotic arms are examples of devices that have been used to augment the loss of function in the upper extremity. Mobile arm supports are linkages designed to support the weight of the arm and assist arm and shoulder motions. They often have a limited range of motion and are difficult to set up and adjust. Wheelchair mounted orthoses may also restrict motion since they fix the shoulder and elbow joint centers of rotation relative to the wheelchair rather than relative to the user. While externally powered robotic arms are commercially available, training users to develop appropriate control strategies has been a significant problem (1). User surveys have indicated a preference toward developing orthoses rather than robotic assistive devices (2).

## STATEMENT OF THE PROBLEM

The goal was to design, develop and evaluate the kinematics of a passive, wearable, four degree of freedom (DOF) arm orthosis. This work was viewed as a first step in the development of a powered arm orthosis that focuses on the needs of persons with muscular dystrophy.

## RATIONALE

Development of a powered, wearable, upper extremity orthosis for persons with DMD has the potential to maximize the use of existing hand and wrist function. A wearable device can more closely match the user's shoulder and arm kinematics than a wheelchair mounted device. Kinematic performance is critical in terms of potential user acceptance. Development of a passive prototype enabled a detailed kinematic study to be conducted prior to addressing the complete spectrum of design issues.

## DESIGN AND DEVELOPMENT

User task priorities were identified from the literature (3) and by conducting interviews with three potential users. To gain user acceptance, an upper extremity orthosis must be useful in positioning the hand to enable daily living activities involving reaching, picking up and manipulating objects as well as feeding and grooming. Issues such as weight and aesthetics were postponed to the next design iteration. The contralateral hand would control a powered version of the orthosis. A conceptual design of a 4 DOF orthosis was developed. The design provided shoulder flexion and abduction, humeral rotation and elbow flexion. A crude physical model was constructed and evaluated. Next, computer aided design software was used to develop a detailed design of the orthosis. A human factors library available in the software was used to model the upper torso. A 3D solid model of the orthosis was created and mounted on the torso. Kinematic constraints were applied to the combined model for each degree of freedom in the orthosis and upper extremity. Various motions were applied to the model to simulate daily living tasks. The design was then refined and detailed drawings were produced (Figure 1). Shoulder flexion is provided by two grooved circular rings (a & b) that slide relative to each other. The outer ring (a) is the ground link and is attached to the body mounting system. Two pin joints (c) are attached to the rotating shoulder ring (b) and provide shoulder abduction. Humeral rotation is provided midway along the humerus by another pair of grooved rings (d & e) that can rotate relative to one another. Pin joints (f) provide elbow flexion. The body mounting system consists of two pieces of ABS that are heat formed to the contour of the user and held in place by straps with buckles (Figure 2). The orthosis weighs 11 lbs.

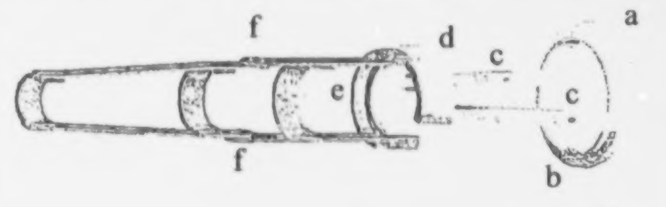

**Figure 1: Annotated diagram of the orthosis. See text for details.**

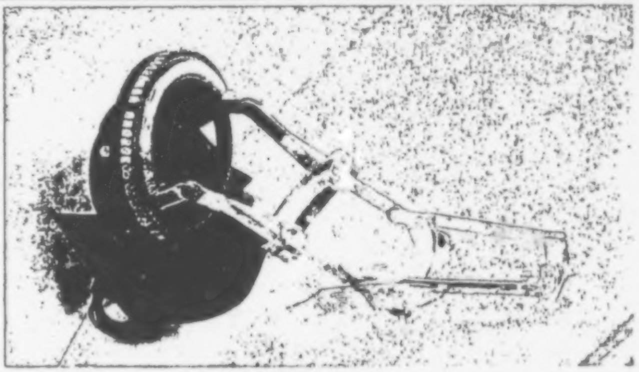

**Figure 2: Picture of the orthosis**

## EVALUATION

The ranges of motion of the individual joints were: shoulder flexion –30°-140°, shoulder abduction 15°-110°, humeral rotation 0°-90° and elbow flexion 0°-125°. These ranges are less than normal but this did not affect the performance of typical activities of daily living. The major limitations resulted from the lack of scapula rotation. Interference was responsible for the restriction on elbow flexion. Tests were conducted to simulate the kinematic performance of the orthosis in daily living activities. The tests assumed that each DOF would be operated sequentially by individual 3 position, center off, switches controlled by the contralateral hand. It was also assumed that, when powered, each degree of freedom would rotate at 10 rpm and there would be a 2 second delay in activating sequential switches. Eight activities were simulated: reaching for and obtaining a book from shelves at 3 different heights, writing at a desk, opening a book on a table, eating with a spoon, reaching for and using a saltshaker and combing hair. Two to four kinematic paths were simulated for each activity. These activities could be accomplished using 4-11 sequential steps and took 9-31 seconds to complete. The majority of time was due to the delay between activating switches. Generally, the quicker paths mimicked the natural motion.

## DISCUSSION

Evaluation the wearable, passive, 4 DOF prototype arm orthosis demonstrated the kinematic feasibility of the design. Even with a simple control strategy of single switches controlling each DOF, activities of daily living could be accomplished within reasonable time frames. Joystick control could improve performance by allowing kinematic coupling of pairs of degrees of freedom and eliminating the delay between activating single switches. Shoulder flexion and abduction could be controlled by a single joystick, as could humeral rotation and elbow flexion. Several activities of daily living such as eating, performing deskwork (reading, writing, etc.) and grooming (combing hair, shaving with an electric razor, etc.) take place where a flat surface is present (i.e. table or laptray). These activities could be performed using the elbow as a pivot point on the surface and employing only humeral rotation and elbow flexion. The next prototype will power elbow flexion and humeral rotation and use a joystick to couple these motions. A major design effort will be directed toward reducing the weight and improving the appearance of the orthosis.

While the primary application of a wearable, powered 4 DOF arm orthosis has been directed towards persons with DMD, the orthosis could prove useful for persons with other types of muscular dystrophy, spinal muscular atrophy or amyotrophic lateral sclerosis. Persons with high-level spinal cord injury, brachial plexus injury, multiple sclerosis or stroke are also potential users.

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# A BACKDRIVEABLE ROBOT FOR MEASURING AND MANIPULATING STEPPING

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## ABSTRACT

We describe a backdriveable robotic device that can measure leg trajectories and apply forces to the leg during stepping on a treadmill. The device makes use of an unconventional mechanism design and a moving coil type linear motor. We demonstrate that the device does not substantially impede stepping, yet can accurately reproduce desired stepping trajectories.

## BACKGROUND AND RATIONALE

Step training with body weight support on a treadmill (BWST) is a promising new locomotion rehabilitation technique. The key characteristics of this training are partial unloading of the legs and assistance of leg movements during stepping. Recent studies indicate that intensive step training with BWST can significantly improve walking ability following spinal cord injury and stroke [1]. However, the technique remains relatively inaccessible because it is labor intensive, requiring two to three therapists to manually assist the patient's legs and torso. Manually assisting in leg motion is also tiring and can cause repetitive stress injuries in therapists. In addition, the assistance provided, and thus the pattern of sensory input to the spinal cord, can vary greatly between trainers and sessions.

To address these issues, several robotic devices have recently been developed for automating step training with BWST. The Mechanized Gait Trainer (MGT) is a singly actuated mechanism that drives the feet through a gait-like trajectory using a doubled crank and rocker system [2]. Different gears can be incorporated to vary stride length and timing. The Lokomat is a motorized exoskeleton that has four rotary joints that drive hip and knee flexion/extension for each leg [3]. The joints are driven in a gait-like pattern by precision ball screws connected to DC motors.

While cleverly designed and useful, these devices lack a key design feature that has distinct advantages for robot-based therapy and assessment. This feature is good backdriveability or, in other words, low intrinsic endpoint mechanical impedance. Potential benefits of good backdriveability are:

- *Assistive Bandwidth*: A backdriveable machine could more easily be made to "fade to nothing" by reducing the amount of assistance provided as patient recovery progresses.
- *Natural Feedback*: A backdriveable device could be controlled in such a way that it deviates from the controlled path when the patient exerts uncoordinated forces, providing direct and natural kinematic feedback of movement control errors.
- *Passive Motion Capture*: A backdriveable device could passively record free stepping in order to quantify recovery progress, acting as a motion capture system.
- *Teach and Replay*: A backdriveable machine could record movements applied by therapists, then robotically replay them.

The MGT is not fully backdriveable because it cannot be driven away from the path specified by its single degree-of-freedom mechanical linkage. The Lokomat is difficult to backdrive because it uses high-advantage, ball-screw actuators. Backdriveability with substantial actuator power is in general difficult to achieve, although some backdriveability can be endowed to a non-backdriveable device by sensing the contact force between the device and the environment, and moving the actuators in order to control that force. The simplest and most robust approach to good backdriveability, however, remains minimizing the friction and inertia of the mechanism and actuators.

## STATEMENT OF THE PROBLEM

The objective of this project was to develop a backdriveable robotic device for measuring and manipulating stepping on a treadmill. Specifically, we sought to develop a device that could generate substantial forces for assisting in stepping, while minimally encumbering the legs.

## DESIGN

Our design for a backdriveable step-training robot is shown in Fig. 1. Two moving coil forcers drive either end of a two bar linkage. The linkage apex is attached through a revolute joint to the bottom of the shoe. The apex can be moved in any desired planar trajectory $x(t)$, $y(t)$ by moving the forcers along linear trajectories $x_1(t)$ and $x_2(t)$, as specified by:

$$x_1(t) = x(t) + \sqrt{l^2 - y^2(t)}$$

$$x_2(t) = x(t) - \sqrt{l^2 - y^2(t)}$$

where $l$ is the length of each link. The planar force $F_x$, $F_y$ applied by the apex to the leg can be controlled by applying forces $F_1$ and $F_2$ with the moving coils:

$$F_1 = 0.5F_x + \frac{(x_2 - x_1)}{4\sqrt{l^2 - (\frac{x_2 - x_1}{2})^2}} F_y$$

$$F_2 = 0.5F_x - \frac{(x_2 - x_1)}{4\sqrt{l^2 - (\frac{x_2 - x_1}{2})^2}} F_y$$

This mechanism design has several advantages. A moving coil linear motor can generate substantial force yet has low backdrive friction, so the device is powerful yet lightweight. In addition, force application can be mechanically constrained to a physical workspace that matches that of the leg during walking (i.e. horizontally wide but vertically short) with simple hard stops or by installing short links. When compared to exoskeletal approaches, the device is more flexible because it can accommodate any size leg and any stepping trajectory with no mechanical adjustments.

## DEVELOPMENT AND EVALUATION

We have built a prototype of this device design called "ARTHuR" – Ambulation-assisting Robotic Tool for Human Rehabilitation (Fig. 1). ARTHuR incorporates moving coil forcers with a mass of 0.32 kg and a peak force of 17.6 kg. The positions of the moving coils are measured using a linear optical encoder with two read heads at a resolution of 5 $\mu$m. The system is controlled using MATLAB's Real Time Windows Target.

To assess the backdriveability of ARTHuR, we measured how much the passive device perturbed stepping trajectories when an unimpaired subject stepped on a treadmill at 0.9 m/s. For comparison, the subject also stepped without the device attached. In both cases,

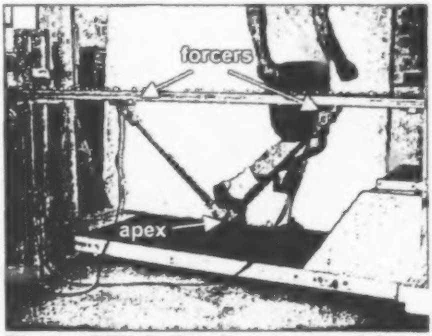

**Fig. 1** ARTHuR: Two linear motor coil forcers drive a two-bar linkage, allowing planar motion control of the linkage apex.

the planar motion of the ankle was measured using a very low friction (< 0.2 N) mechanical digitizing linkage. Stepping trajectories were similar with and without ARTHuR attached, with small differences at toe off and heel strike (Fig. 2). The backdrive friction of the device was measured to be 3.4 N.

To test the ability of ARTHuR to assist in stepping, we recorded stepping trajectories from the unimpaired subject at 0.9 m/s on the treadmill using the device, then actively tracked the trajectories with a proportional-derivative position controller. ARTHuR reproduced the recorded steps with a mean tracking error of 1.3 mm.

## DISCUSSION

The device described in this paper does not substantially impede stepping, yet can accurately reproduce desired stepping trajectories. By virtue of these features, it provides a useful tool for studying locomotion rehabilitation. Future research will seek to use the device to automate step training with BWST by further developing both the mechanical and software interfaces between the robot and patient. For example, although the foot was chosen as the attachment point for convenience in the initial testing of the device, attaching the device to the lower shank may provide a more normative pattern of sensory input, as has been found with a robotic step device for spinal injured rats [4]. Attaching at the lower shank would also allow loading information at the foot to be enhanced during stance [5]. Software cancellation of dynamic friction and inertia may further enhance the device's backdriveability. Designing control software that maximizes the capacity of the nervous system to relearn stepping following injury will be a key challenge.

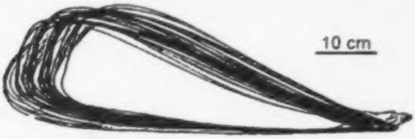

**Fig. 2** Step trajectories measured at the ankle with (black line) and without (grey line) ARTHuR attached. Twenty steps are shown for each case.

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# EVALUATION OF SENSORS FOR A SMART WHEELCHAIR

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## ABSTRACT

Seven sensors were evaluated to determine their ability to detect obstacles at different distances and angles. The Polaroid 600 and 9000 sonar sensors and Sharp GP2D02 and GP2D12 infrared sensors were evaluated for eight materials and four obstacle widths. The Massa E152/40, Sonaswitch Mini-A, and Devantech SRF04 sonar sensors were evaluated for a single condition.

## BACKGROUND

Some individuals find it difficult or impossible to operate a standard power wheelchair (1). To accommodate this population, several researchers have developed "smart wheelchairs" which can detect objects in the environment and assist with obstacle avoidance, path following, or tasks such as moving through doorways (2). A smart wheelchair will only be as effective as its sensors. Sensor varieties could include traditional sonar, wide-beam sonar, infrared, bump sensors, and computer vision. It is important to understand the performance of these sensors under different conditions, so that a smart wheelchair will be able to assist people in a variety of environments.

## RESEARCH QUESTIONS

Research is being conducted to evaluate a variety of commercially available sonar and infrared sensors. Characteristics of interest include minimum and maximum distances at which the sensor can detect an obstacle and the field of view of the sensor. The goal of this research is to measure these characteristics for a variety of sensors, a variety of materials which a smart wheelchair may encounter, and a variety of obstacle sizes.

## METHOD

A series of tests were performed on four sensors: the Polaroid 600 sonar transducer (Polaroid, Cambridge, MA); the Polaroid 9000 wide-beam sonar transducer; the Sharp GP2D02 digital output infrared sensor (Sharp Electronics, Mahwah, NJ), and the Sharp GP2D12 analog output infrared sensor. Polaroid sensors were used in conjunction with the Polaroid Ultrasound Developers' Kit.

The range of each sensor was evaluated for a number of materials (Table 1). The sensor was initially positioned one meter from the obstacle, then moved toward the obstacle until the sensor no longer provided an accurate reading. The distance between the sensor and the obstacle was recorded as the minimum detection distance. The sensor was then moved away from the wall until the sensor no longer provided an accurate reading, and the distance between the sensor and the wall was recorded as the maximum detection distance. This test was repeated ten times for each sensor and each material condition.

The field of view of each sensor was evaluated for each material. Field of view was measured by the range of angles over which the sensor could detect a flat obstacle. Sonar sensors were placed 1 meter from the obstacle and infrared sensors were placed 8 cm from the obstacle. The angle between the sensor and the wall (θ in Figure 1) was varied starting from zero degrees (i.e. sensor perpendicular to the wall) and turning the sensor counterclockwise until the sensor no longer provided an accurate

Table 1: Materials tested and dimensions of obstacles.

| Material | Width | Height | Depth |
|---|---|---|---|
| Bare drywall | 48" | 24" | 0.5" |
| White drywall | 48" | 24" | 0.5" |
| Black drywall | 48" | 24" | 0.5" |
| Wood | 48" | 24" | 0.25" |
| Glass | 36" | 12" | 0.1" |
| Carpeting | 60" | 24" | 32.5 oz face wt. |
| Marble | 32" | 9.5" | 1" |
| Brick | 15.5" | 7" | 3.75" |

reading. The sensor was then turned clockwise until the sensor no longer provided an accurate reading. This procedure was repeated ten times for each obstacle.

Each sensor's detection angle was also measured using cardboard panels of varied width. Each panel was 2 meters long and 2 millimeters thick. Widths were 1.25 cm, 2.5 cm, 5.0 cm and 10.0 cm. The detection angle was measured as with the larger obstacles.

Preliminary evaluation was performed for three additional sensors. Minimum and maximum distance and field of view for the Massa E-152/40 (Massa Electronics, Hingham, MA) were measured for the bare drywall obstacle. Minimum and maximum distance and beam width were measured for the Sonaswitch Mini-A sensor (EDP Company, Livonia, MI) and the Devantech SRF04 (Robot Electronics, Norfolk, UK). Beam width was measured by moving targets toward the axis of the sensor (the horizontal line in Figure 1) from the left and the right side until the sensor detected the obstacle. Objects were moved into view until the sensor appeared to have at least a 50% probability of detecting the obstacle.

## RESULTS

Minimum and maximum ranges of each sensor for each material condition are shown in Table 2. The Massa sensor had a minimum detection distance of 35.4 ± 2.1 cm and a maximum detection distance of 333.2 ± 24.8 cm for bare drywall. The Sonaswitch sensor had a minimum detection distance of 20.3 cm and a maximum distance of 99.1 cm. The Devantech sensor had a minimum detection distance of 2.5 cm and a maximum distance of 129.5 cm. Field of view (clockwise plus counterclockwise detection angles) are shown in Table 3 for each material condition, and in Table 4 for each size condition. The Polaroid 9000 was unable to detect the 1.25 cm wide obstacle, and the Polaroid 600 could only detect this obstacle 90% of the time. The Massa sensor had a total detection angle of $39.9^0 \pm 4.7^0$. The Sonaswitch sensor had beam widths of 21.6 cm at an obstacle distance of 0.3 m, and 27.9 cm at an obstacle distance of 0.61 m. The Devantech sensor had beam widths of 11.4 cm at an obstacle distance of 0.3 m, and 26.0 cm at an obstacle distance of 0.62 m.

Minimum detection distance for the GP2D12 was significantly lower than all other sensors ($p<0.05$ for Analysis of Variance using Fisher's Method). Minimum distance was significantly lower for GP2D02 than either ultrasound sensor ($p<0.05$), and for Polaroid 600 compared to Polaroid 9000 ($p<0.05$). Maximum distance was significantly higher for the ultrasound sensors compared to the infrared sensors, while detection angle was significantly higher for the infrared sensors compared to the ultrasound sensors ($p<0.05$). There were no significant material differences across sensors for detection range, although the minimum detection distance was significantly lower for carpeting compared to the majority of other materials for the Polaroid 600, GP2D02, and GP2D12. Differences in detection angle across materials may have been confounded by the different obstacle widths.

## DISCUSSION

While the infrared sensors were able to detect closer obstacles and detect large obstacles at greater angles, the ultrasound sensors were able to detect obstacles at a larger distance. The Polaroid 9000 wide-beam sonar was able to detect small obstacles (2.5 to 10.0 cm) at a greater angle than the other sensors, but was unable to detect the 1.25 cm obstacle. The sensors also tended to react to materials in different ways. The GP2D12 in particular had difficulty detecting glass, black drywall, and black marble (significantly larger minimum and smaller maximum detection distances, $p<0.05$). The Sharp infrared sensors will be evaluated under different lighting conditions, since infrared detectors are sensitive to

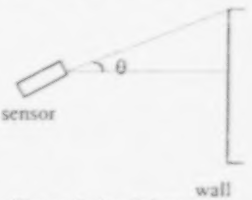

Figure 1: Angle between sensor and obstacle

light. Further evaluation will also be performed for the Sonaswitch, Massa, and Devantech sensors.

Because of these differences between sensors, it would be beneficial to incorporate a variety of sensors into a smart wheelchair system. One limitation of this study is that all obstacles were stationary relative to the sensors. When incorporated in a smart wheelchair, the sensors will be moving relative to the obstacles, either because the sensors themselves are moving (on the wheelchair) or the obstacles are moving (e.g. people). Therefore, these results represent the best performance that can be expected for the sensors in real-world situations.

Table 2: Minimum and maximum detection distances across sensor models and obstacle materials. Values given as mean minimum ± standard deviation; mean maximum ± standard deviation. All measurements are in centimeters.

| | Polaroid 600 | Polaroid 9000 | Sharp GP2D02 | Sharp GP2D12 |
|---|---|---|---|---|
| Bare drywall | 8.1 ± 0.7; 275.7 ± 13.2 | 25.6 ± 0.6; 385.1 ± 16.1 | 3.0 ± 0.9; 56.8 ± 28.1 | 0.6 ± 0.1; 98.9 ± 13.1 |
| White drywall | 8.2 ± 0.6; 362.8 ± 35.7 | 24.0 ± 0.6; 425.5 ± 57.2 | 2.9 ± 1.2; 62.7 ± 33.3 | 0.3 ± 0.2; 115.8 ± 10.8 |
| Black drywall | 8.4 ± 0.4; 310.8 ± 19.5 | 24.6 ± 2.5; 493.7 ± 26.7 | 3.0 ± 1.2; 72.3 ± 48.3 | 3.5 ± 0.2; 30.9 ± 0.1 |
| Wood | 8.5 ± 0.6; 357.8 ± 39.9 | 26.7 ± 2.5; 496.2 ± 4.4 | 2.8 ± 1.2; 62.9 ± 34.6 | 0.3 ± 0.1; 100.2 ± 16.7 |
| Glass | 8.6 ± 0.6; 363.5 ± 43.0 | 26.0 ± 0.4; 371.9 ± 33.2 | 1.8 ± 1.8; 70.4 ± 51.9 | 2.6 ± 0.2; 28.2 ± 5.8 |
| Carpet | 7.7 ± 0.5; 340.0 ± 35.5 | 25.6 ± 0.2; 295.4 ± 15.0 | 0.1 ± 0.03; 63.6 ± 34.4 | 0.2 ± 0.1; 89.8 ± 16.3 |
| Marble | 7.9 ± 1.2; 336.0 ± 11.7 | 25.4 ± 1.7; 490.0 ± 14.7 | 3.3 ± 0.9; 92.1 ± 67.2 | 2.9 ± 0.6; 39.2 ± 1.3 |
| Brick | 8.3 ± 0.3; 373.2 ± 45.5 | 25.6 ± 0.9; 337.4± 47.8 | 3.5 ± 0.8; 48.8 ± 20.7 | 1.0 ± 0.1; 61.4 ± 1.9 |

Table 3: Detection angle across sensors and across obstacle materials.

| Material | Polaroid 600 | Polaroid 9000 | Sharp GP2D02 | Sharp GP2D12 |
|---|---|---|---|---|
| Bare drywall | $55.7^0 \pm 4.3^0$ | $68.7^0 \pm 3.2^0$ | $141.4^0 \pm 10.4^0$ | $151.1^0 \pm 1.7^0$ |
| White drywall | $57.2^0 \pm 4.4^0$ | $71.7^0 \pm 5.3^0$ | $144.1^0 \pm 12.9^0$ | $155.0^0 \pm 1.7^0$ |
| Black drywall | $56.6^0 \pm 3.8^0$ | $79.4^0 \pm 2.8^0$ | $143.9^0 \pm 12.3^0$ | $121.2^0 \pm 1.7^0$ |
| Wood | $59.8^0 \pm 3.6^0$ | $63.8^0 \pm 2.0^0$ | $142.0^0 \pm 10.5^0$ | $154.1^0 \pm 1.9^0$ |
| Glass | $54.5^0 \pm 4.4^0$ | $55.9^0 \pm 5.6^0$ | $124.1^0 \pm 15.1^0$ | $72.7^0 \pm 18.8^0$ |
| Carpet | $68.5^0 \pm 6.3^0$ | $30.4^0 \pm 4.0^0$ | $145.4^0 \pm 10.8^0$ | $157.0^0 \pm 2.9^0$ |
| Marble | $68.6^0 \pm 5.1^0$ | $95.2^0 \pm 10.7^0$ | $135.1^0 \pm 8.2^0$ | $128.2^0 \pm 4.5^0$ |
| Brick | $55.3^0 \pm 5.8^0$ | $57.3^0 \pm 8.6^0$ | $115.7^0 \pm 4.3^0$ | $117.3^0 \pm 2.1^0$ |

Table 4: Detection angle across sensors and across obstacle widths.

| Obstacle Width | Polaroid 600 | Polaroid 9000 | Sharp GP2D02 | Sharp GP2D12 |
|---|---|---|---|---|
| 1.25 cm | $21.9^0 \pm 4.4^0$ | N/A | $18.7^0 \pm 3.6^0$ | $15.5^0 \pm 4.0^0$ |
| 2.5 cm | $21.6^0 \pm 2.3^0$ | $27.6^0 \pm 3.7^0$ | $23.9^0 \pm 5.5^0$ | $19.1^0 \pm 5.6^0$ |
| 5.0 cm | $23.0^0 \pm 2.9^0$ | $55.9^0 \pm 4.6^0$ | $33.7^0 \pm 3.4^0$ | $23.0^0 \pm 2.7^0$ |
| 10.0 cm | $47.7^0 \pm 4.7^0$ | $68.3^0 \pm 4.1^0$ | $48.4^0 \pm 7.2^0$ | $43.8^0 \pm 7.6^0$ |

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# DYNAMIC PRESSURE RELIEF FOR THE WHEELCHAIR USER WITH LONG-TERM THERAPEUTIC NEUROMUSCULAR ELECTRICAL STIMULATION.

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## ABSTRACT

Motor and sensory paralysis due to spinal cord injury (SCI) causes many physiological changes below the level of the lesion that contribute to an overall reduction in tissue health. Reduced mobility and muscle atrophy are among the many changes that increase the risk of tissue breakdown and pressure sore development in this patient group. Neuromuscular electrical stimulation (NMES) provides a unique pathway for improving the characteristics of paralyzed muscle by altering intrinsic characteristics. Advanced implantation technologies have been employed for long-term therapeutic use to provide a complimentary method for dynamic intrinsic improvement of tissue health and seated pressure relief.

## BACKGROUND

Pressure sores are widely recognized as one of the most significant secondary complications of SCI. The occurrence of tissue breakdown frequently requires extended periods of bedrest and this alone can have a major negative impact on the overall quality of life of the individual. In addition there are often appreciable economic and psychological costs for the carer and/or society (1).

Historically, a range of support cushions have been developed with the common overall goal of preventing the incidence of pressure sores by improving external applied pressure at the user/support interface. The majority of these devices employ static redistribution of pressure using compliant materials and/or contouring. Some cushions provide dynamic pressure relief through cyclic variation in cushion surface characteristics, e.g. inflation/deflation of an air-cell matrix. However, despite the many materials advances that have been achieved, the alteration of extrinsic conditions at the user/support interface cannot alter the intrinsic status of paralyzed muscle, i.e. the tissue viability, and the incidence of pressure sore development remains high (2).

NMES has been previously employed primarily for directly functional applications. It has also been observed, however, that long-term use of NMES will increase the strength and bulk of the stimulated muscle. Thus the intrinsic properties of a paralyzed muscle can be altered using this technique. In addition, extrinsic factors, such as interface pressure distribution, can be affected by employing dynamic stimulation paradigms. The primary site for tissue breakdown in the wheelchair user is in the pelvic region, in particular over the ischial tuberosities.

## RESEARCH QUESTION

The objective for the current study is to investigate the hypothesis that long-term use of dynamic NMES using an implanted gluteal stimulation system can provide regular periodic variations in seating interface pressure distributions and produce a sustained improvement in regional tissue health. Concurrently, long-term use of therapeutic NMES increases regional vascularisation leading to improved regional blood flow and higher tissue oxygen levels together with increases in muscle bulk and reduced peak regional interface pressures.

## METHOD

Subject selection criteria for this study include a complete motor and sensory spinal cord injury above the level of T12 and more than one year post-injury. Individuals with significant systemic disease, such as diabetes or heart disease are ineligible, however those with a history of pressure sores may participate provided they do not have an open wound at the time of enrollment in the study.

A 4-channel percutaneous electrode system is implanted bilaterally in the gluteus maximus. The procedure is carried out on an outpatient basis, with discharge to home one hour after the procedure is completed. The patient is then required to maintain full bedrest for 2 –3 days followed by limited mobility for one week before commencing the stimulation regime.

Following muscle conditioning to improve strength and fatigue resistance, the NMES system is used daily in the wheelchair. Stimulation parameters are set to mimic pressure-relief maneuvers through active muscle contractions. Tissue health is monitored regularly using a triad of quantitative assessment techniques; Regional blood flow is evaluated using a *TINA TCM3-2 monitor* (Radiometer USA Inc., Cleveland OH). The oxygen electrode (Radiometer, model E5280-8) was calibrated using a gas containing 20.9% $O_2$/5% C $O_2$ in nitrogen. System temperature control was set at 43°C, in order to produce maximal local vasodilation and room temperature over the course of each assessment is maintained at 25±2°C. Seated interface pressure is monitored using the *Tekscan Advanced Clinical Seating System* (Tekscan Inc., Boston MA). This measurement system employs thin flexible sensors utilizing conductive and semi-conductive inks in a grid-based array. The array contains more than 2000 sensors and operates within the range 1-250mmHg (accuracy ±10%) at scanning rate of 125Hz. Real-time 3-D images of pressure distribution at the seating interface are produced using graphical display software. The system analysis can also determine peak regional pressures, maximum pressure gradient and contact area. Muscle thickness is determined using transverse section CT scans through the gluteal muscles at pre-defined bony landmarks.

## RESULTS

Three subjects have currently been recruited to this study. One particpant has been using the gluteal stimulation system for over four years and has had no incidences of skin breakdown or pressure sores during this time. The other two participants have been using the system for under a year.

Baseline tissue health characteristics are obtained by laboratory assessment prior to commencing use of NMES. Serial assessments of variables of interest are then carried out at regular intervals during the course of the study. Primary variables of interest include:

- Mean unloaded tissue oxygen level (over the ischial tuberosity).
- Mean overall user/support interface pressure
- Peak ischial region/support interface pressure

These variables are determined for each assessment and changes during dynamic stimulation and over time are determined. Dynamic variations in peak regional interface pressures are found to mirror the pattern of active gluteal contractions produced by dynamic NMES. In addition, static pressure distribution at the user/support interface is found to become more uniform over time, with marked reductions in peak pressures under the ischia.

## DISCUSSION

The application of dynamic NMES when seated in the wheelchair provides an intrinsic means for periodic variations of pressure distributions in the seated posture. Thus, this technique may provide a useful adjunct pressure relief technique for individuals at increased risk of pressure sore development, in particular those who cannot move independently.

Assessment of tissue health characteristics has also shown sustained positive changes in ischial region tissue health, concurrent with regular gluteal stimulation. These results imply that long-term therapeutic application of NMES may reduce the risk of pressure sore development due to intrinsic changes in the paralyzed muscle.

Current indications are that regular use of NMES stimulation is likely to be necessary in order to achieve optimal benefit to tissue health.

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# DEVELOPMENT OF A NOVEL TYPE REHABILITATION ROBOTIC SYSTEM KARES II

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## ABSTRACT

In this paper, we introduced our wheelchair based robotic arm system, KARES 2. This system is a novel type in the sense of its dual type configuration. KARES 2 combines many advantages of conventionally well-known rehabilitation systems. And it also includes many human-robot interaction technologies to assist a daily life of the disabled and the elderly. User can utilize one or combination of interaction technologies according to one's physical level of disability. With integrated system, we successfully performed some fundamental tasks for the disabled and the elderly.

## BACKGROUND

Since 1998, KARES (KAIST Rehabilitation Engineering Service System) II has been developing as a new wheelchair-based robotic arm system, and its human-robot interaction technologies which assist independent life of the elderly and the disabled persons that have disadvantages to sensory and motor functions of their limbs. The wheelchair robot system consists of a powered wheelchair and a robotic arm (Figure 1). It has not only a mobile capability through the motorized wheelchair but also a manipulatory function with the robotic arm. Since a user and a robot in the same environment, safe and comfortable interaction with robots is important. It has been reported that many difficulties exist in human-robot interactions in existing rehabilitation robots (1)(2). For example, manual control of the robotic arm takes a high cognitive load on the user part while physically disabled persons may have difficulties in operating joysticks dexterously or pushing buttons for delicate movements. Therefore, human-robot interaction is one of essential technologies to be developed in using the robot system.

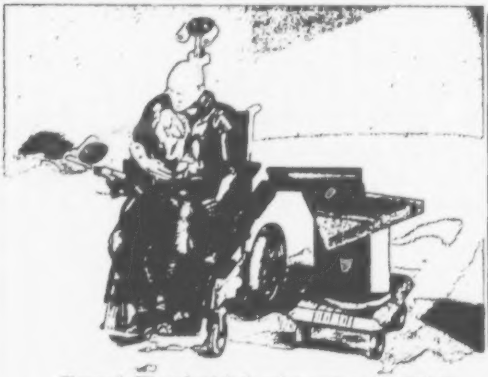

Figure 1: The wheelchair robot system, KARES II.

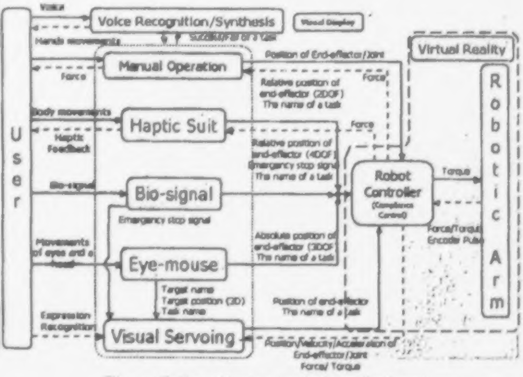
Voice
Voice Recognition/Synthesis
Hands movements
Manual Operation
Force
Position of End-effector/Joint
Relative position of end-effector (2DOF)
The name of a task
Force
Virtual Reality
Body movements
Haptic Suit
Haptic Feedback
Force
Relative position of end-effector (4DOF)
Emergency stop signal
The name of a task
U s e r
Bio-signal
Bio-signal
Robot Controller
(Compliance Control)
Torque
Emergency stop signal
Absolute position of end-effector (3DOF)
The name of a task
Force/Torque
Encoder Pulse
Movements of eyes and a head
Eye-mouse
Target name
Target position (3D)
Task name
Position of end-effector
The name of a task
Expression Recognition
Visual Servoing
Position/Velocity/Acceleration of End-effector/Joint
Force/Torque
Robotic Arm

Figure 2: Input/output relation of subsystems for human-robot interaction

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Two factors are essential in intelligent human-robot interaction technology; one is intention reading of the user, and the other is autonomous capability of the robot. Intention reading allows the user to command to the robot system in a human-friendly way possibly by using bio-signal, wearable haptic suit, voice/sound perception, or the "eye" mouse device that utilizes eye movements (3). Intention that is read can be used as a system state feedback for human-robot interaction. The autonomous capability in controlling the robot system is needed to realize the user's commands when the user has a limited physical ability. A typical example is visual servoing-based or compliance-based control of a robotic arm (3).

## HUMAN-ROBOT INTERACTION TECHNOLOGIES

As mentioned above, our rehabilitation system consists of several subsystems such as the eye-mouse, the haptic suit, the bio-signal(EMG: electromeogram) recognition module, and the compliant robotic arm with visual servoing capability. Fig. 2 shows the input/output relation of subsystems for human-robot interaction. For example, the task to serve a meal for a user is conducted as follows: First, the eye-mouse reads the user's intention, and transfers processed information, such as the position of a desired food, to the visual servoing module. Next, the visual servoing module controls the robotic arm to spoon up the food and moves it to the user's mouth. Consequently, the intention reading of the user and autonomous capability of the robotic arm should well be coordinated to perform the task successfully.

Among those human-robot interaction technologies, the eye-mouse, the haptic suit and the EMG recognition module are categorized into direct input devices for the user. And the user can select only one or combination of these technologies with respect to his/her level of disability. For example, if the user can't move the body except above the neck, the bio-signal based control system is the only one to control robotic arm, wheelchair, and so on.

## INTEGRATION OF SUBSYSTEMS

KARES 2 is a novel dual type rehabilitation system in the sense of its configuration. KARES 2 consists of the wheelchair part and the mobile platform part. This means that KARES 2 combines many advantages of the conventionally well-known rehabilitation systems such as mobile-based type (4) and fixed workstation type (5). Specifically, KARES 2 is free from the vibration of the robot base with mobile platform which is a very serious problem of the conventional mobile-based (or wheelchair-based) rehabilitation system. And with mobile platform, KARES 2 can perform various tasks which cannot be possible using the conventional wheelchair-based or fixed workstation type rehabilitation system.

The wheelchair part contains powered wheelchair with various human-robot interfaces such as eye-mouse, haptic suit, and bio-signal based control system. And in this part, there is a 3D position extraction system with stereo matching techniques. This 3D position extraction system is to extract 3D position data around the system and the user, to provide necessary visual information as a visual feedback to the user and the robotic arm during manipulation. The mobile platform can provide a manipulability with soft robotic arm and a mobility with its own wheel. The user can maneuver the mobile platform with his/her own intention. And in some tasks, the eye-in-hand-camera of the robotic arm performs a visual servoing.

Finally, we performed some predefined tasks with integrated system. For this purpose, we have been surveyed necessary tasks from the disabled and the elderly. The experiments are successfully performed with the able-bodied. And we also have a plan to test KARES 2 with the disabled and the elderly in the near future.

## DISCUSSION

KARES II is a wheelchair based robotic system to assist the activities of daily life for the disabled. On the basis of the predefined tasks of the wheelchair based robotic system, the design of the robotic arm and visual servoing techniques to control the robotic arm have been applied.

The new robotic arm and visual servoing of the robotic arm provide the system with autonomous capability. Then in order to interact with the robotic arm, three types of human-robot interfaces, such as an eye-mouse, an EMG interface, and a haptic suit, well recognize eye movements, electrical signals of muscles, and body motions, respectively.

Specially, spinal cord injured persons can select desirable interfaces in accordance with one's preference. KARES II has a large amount of possibility to assist the disabled and the elderly.

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# WREX – A CASE STUDY OF THE WILMINGTON ROBOTIC EXOSKELETON.

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## ABSTRACT

This paper presents a case study of the Wilmington Robotic Exoskeleton (WREX) after a 10-day user trial. The WREX is a Functional Upper Arm Orthosis developed at the duPont Hospital for Children in Wilmington, DE. The Jebsen Standardized Hand Functional Test for Children was conducted prior to and upon completion of the 10 day trial. The results of the test as well as the subjective impressions regarding the WREX will be discussed. Several design and implementation issues were raised by this initial trial. The subject's enthusiasm and drive highlighted practical issues both pro and con. This input is invaluable in developing a usable and acceptable assistive device such as the WREX.

## BACKGROUND

The WREX is a gravity balanced orthosis that uses bungee cords, described in detail in reference [1,2]. It consists of two main units, a forearm and an upper-arm, connected by a single degree of freedom elbow joint, as shown in Figure 1. This is then attached to a two degree of freedom shoulder joint. This variable shoulder joint allows for misalignment and limb length discrepancies between the users and the orthosis. Most of its components are machined from black Delrin plastic. This material is an acetal homopolymer material known for its excellent dimensional stability and ease of fabrication. Delrin is about half the weight of the aluminum used in some of the earlier orthoses. The medium sized orthosis used in this trial weighs less than 2 lbs. The WREX is mounted to the chair using a modified camera clamp attached to a rod and bracket system. The latter is common to wheelchair device and pad fixturing. The user's arm was fitted to the WREX using a semi-custom polyethylene plastic arm trough. Rather than cast and fit every individual for future studies, a sampling of three different size ranges was casted. The easily heat formable plastic was than molded over the appropriate cast positive, adjusted and custom fit to the individual.

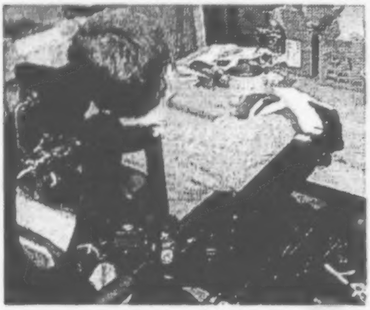

**Figure 1.**
**WREX with subject performing Jebsen test.**

The subject [SS] is an 11 year old boy with Spinal Muscular Atrophy (SMA) who uses a wheelchair. He weighs 65 lbs and he has good strength though weaker in the triceps than the biceps. He manages to perform most tasks independently by compensatory movements. He has difficulty lifting heavier objects and elevating his elbows. He is very enthusiastic about participating in the project and testing the WREX. His parents are very supportive of the project. The results of his initial Jebsen test prior to the trial show fair ability in the seven tasks tested. These tests were performed without the WREX.

## DESIGN QUESTIONS

The primary design issue is the battle between making a custom design versus a one-size-fits-many concept. The WREX takes a blended approach. We have scaled the orthosis in three different sizes; small, medium and large versions. Though this does accommodate almost all users, there are a few who lie in-between. To accommodate for this discrepancy a two-degree-of-freedom shoulder joint is used. This assembly is a simple horizontal pivot comprising three links in series. The purpose is to allow for misalignment and still allow free rotation at the shoulder. In most cases where the upper link reasonably matches the user's upper arm this joint works well, providing fluid, transparent action to the user. In those instances were the discrepancy is more substantial the action at the shoulder is decidedly awkward. The upper link of the orthosis will sometimes swing out or sometimes swing in at the shoulder. Though in most cases this doesn't directly hinder the users range of motion, the action sometimes is awkward enough to be inhibiting.

Mounting the WREX to the user's chair is problematic. The shoulder pivots must be aligned to the users shoulder and remain horizontal. However, this is not always possible since the mounting location on the chair varies greatly between users because of different chair configurations. Additionally, this mounting frame most be both rigid, to support a spring-loaded moving orthosis, and flexible enough to connect two disparate points in space. Also desirable was keeping it unobtrusive and easy to detach from the chair when not used. The mounting system consisted of half-inch diameter rod that could be bent and cut to length. These sections were then joined with simple clamps to achieve the shortest and most robust layout possible.

## RESEARCH QUESTIONS

The ultimate test of the design is how well it is received by the user. Does each user need a custom fitted orthosis or can the design be further modified to get a better balance between custom and generic? What tasks can now be accomplished with the WREX that could not before? How much training or preparation is necessary for the user to become effective with the WREX? Do the kinematics of the WREX correspond and compliment the user's or does it interfere and require adjustment?

## METHOD

Prior to taking the WREX home for trial SS was given the Jebsen test without orthotic assistance. The Jebsen test is a set of standardized manual dexterity tasks with norms against which users can be objectively compared. Testing is done using tasks representing everyday functional activities[3]. Using a medium size arm positive mold a polyethylene plastic and foam lined sleeve was vacuum formed. The resulting orthotic was then cut and trimmed and the shape adjusted slightly for a better fit. The result was an arm trough that was close to custom without the time and expense of a custom cast mold. The arm trough was then fitted to a medium size WREX. Although the small size WREX had a better arm to orthosis link length correlation, the medium size was chosen for it's weight balancing capacity. The WREX was then mounted to SS's chair. We tested and adjusted the layout to best suit SS and his activities. After some practice and constructive playing he took the WREX home for 10 days of unstructured use. When SS returned, we met to discuss issues that arose and to run the Jebsen test again with the WREX. SS, his mother and father all contributed valuable insight to the activities and problems encountered during the trial period.

## RESULTS

SS was very enthusiastic about his involvement in the orthosis research. Even though there were many activities that he was capable of doing without it, he felt it was helping him in general. Tasks that improved with WREX were: eating, typing, writing, playing chess and controlling his powered wheelchair[2]. He suggested that the 10 day trial period was too short to get a proper evaluation. Though when questioned about usage SS said that it was sporadic and that he used it more the first couple of days and tapered off after that. One of the issues that SS brought up in the post-trial interview was that the length of the upper arm link was too long and did not allow him to reach certain areas close to his body with ease. When asked to show where the orthosis was hindering his efforts it was unclear to what extent. Despite this SS was pretty certain that if the upper arm link matched the length of his upper arm than all would be well and he would be able to do more with it. There was a difference of about one inch between the length of his upper arm and the length of the upper link of the orthosis. The articulated shoulder joint was able to compensate for some, but not all of this difference. The result was that when SS would pull his right hand back to touch his right side the shoulder joint would flop to the outside instead of staying aligned to the shoulder. Though he seldom needed to go back as far as needed to create this effect, the resulting "awkwardness" of the orthosis sticking out at the shoulder was an issue that SS felt hindered his experience.

The Jebsen test results after the trial showed a slight but encouraging improvement over those taken prior. The testing prior to the trial was without the use of the WREX, while the testing after used the WREX. In the card turning task, devised to simulate page turning, SS improved by more than 3 seconds. This task requires turning four 3 x 5 index cards over. Initially, SS turned over three cards in 7 seconds and the fourth in 16.5 total seconds. The nine and one half second difference between the third and fourth cards was due to compensatory repositioning movements to reach the more distant cards. The norm for this task with the dominant hand is 5 seconds plus or minus 1.1 seconds.

When tested with the WREX after the user trial, SS recorded a time of 13 seconds for four cards. The motion was more fluid and did not require extra assistance to reach all the cards. In the stacking checkers task the results were more visible. This task calls for stacking 4 standard checkers in a pile and timing the activity. Prior to the trial SS placed the four checkers in a horizontal row in 21 seconds. Again it was necessary for SS to leverage the heel of his hand with his other hand to get the extension. The time for this same task using the WREX after the trial took only 9 seconds. SS was also able to stack all 4 checkers during this time. The standard for this task is 3.4 seconds plus or minus 0.5 seconds. Though these results are still well off the norm they are encouraging nonetheless.

## DISCUSSION

Creating an effective functional upper arm orthosis presents a large number of variables in the design process. Simply looking at the users arms there are a myriad of sizes, shapes, and individual kinematic schemes possible. Then add in the complex motion of the shoulder since it is not a simple ball and socket joint. Aligning and fitting an exoskeleton based orthotic system such as the WREX without customizing every component can be quite a daunting endeavor. The time involved in machining and customizing every component would be overwhelming in its own right. The real question seems to be, where is the balance between how much can be generic and how much must be custom fitted.

Another observation noticed that one range of motion or kinematic set that might serve one user well might not work so well for another with different muscle weakness profiles. Further confounding the customization argument. The question then becomes, how does the orthosis dictate the users range of motion schema? Conversely, how much of a difference is acceptable or even tolerable?

Add to all of these design variables the intangible human perception. What the user perceives are the strong or weak points of a particular design. This is a question asked of most every design, but of particular importance where the design becomes so intimate with the user. Work continues on further testing with more subjects.

## ACKNOWLEDGMENTS

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# ESTABLISHING DESIGN CRITERIA FOR INPUT CONTROL SYSTEMS FOR INDIVIDUALS WITH QUADRIPLEGIA

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## ABSTRACT:

There are many devices available to aid individuals with physically limited abilities in their attempts to perform a variety of daily tasks. However, persons with severe disabilities have found many input devices for control of assistive systems to be extremely difficult if not impossible to use; thus, their ability to function in an independent manner has been very limited. Many reasons exist for this failure of some assistive device to perform their intended function but one prime reason is that the capabilities and limits of severely disabled individuals has not been statistically quantified and documented. The intent of this study was to begin to establish preliminary design criteria characterizing the mobility, skills, and strength of individuals with quadriplegia or similar disabilities using their chin or lips to obtain the desired control function.

## BACKGROUND:

Many devices exist to facilitate the daily living and vocational activities for persons with spinal column injuries, however, these devices usually require a care-provider for setup and initialization. Often the devices are found to be difficult to employ, if not unusable, for their intended function. For example, clinically it has been found that 9 to 10 percent of patients who receive power wheelchair training find it extremely difficult or impossible to use the chair for daily activities. When asked specifically about steering or maneuvering, 40% of patients report that it is difficult or impossible. Nearly 85% of clinicians report seeing patients who cannot use power wheelchairs because they lack the requisite motor skills, strength or visual acuity **(1)**.

It is likely that the process of development of control devices has been one of "enlightened" chaos based primarily on the method of trial and error followed by re-evaluation, device modification and repeating this cycle. A designer or inventor may have an idea of a control device, builds the device, and then performs field tests to see if the device is acceptable. The common computer mouse is an example of a device that was developed in this way **(2)**, and continues to be refined, modified and tested **(3)**.

## RESEARCH QUESTION;

Many devices available for severely disabled individuals have been found inappropriate for continuous use. The question arising is why are so many good ideas unable to enhance the independence of their intended users? It may be that clear and readily available design criteria and data has not been the guiding requirement of the product development.

## METHOD:

Typically a control system interface has two distinct parts. There a physical interface that is directly controlled by the user. In a system using a joystick, the physical part would include the joystick, and the associated electro-mechanical components necessary to send electric signals

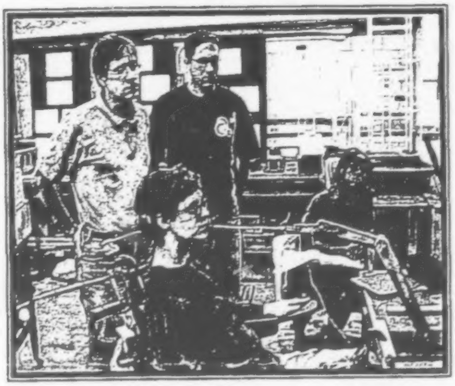

Figure 1.) Subject Testing with "Joystick" Transducer

indicating joystick position to the control system electrical or digital interface. This electrical interface is the second part of the system and is often referred to as the virtual interface. Its intent is to convert the electrical signals from the physical part of the control interface into usable information for the device that is to be controlled. This research focuses on the specific objective of producing information that can be used in the development of the physical interface.

In the design, and subsequent use of a physical interface it is extremely important to understand the capabilities of the user. Some of these capabilities can be quantified such as the range of motions or acceptable force levels to induce movements in the physical interface. This quantification is most valuable when a statistically significant group of subjects is employed to develop a benchmark of motions and interface input forces. This is a description of such an effort.

Two electrical resistance strain gage based transducers were designed, fabricated, calibrated and employed in a test sequence to define the "comfortable" range of motions and forces that can be achieved with a isometric, chin activated "joystick". The stiffness of each transducer was intentionally different to investigate the effect of motion resistance on the perceived comfort of the device. In these preliminary studies a group of 12 subjects were ask to perform a continuous head motion approximating a circular pattern with vertical and lateral head movement. The strain gaged based transducers produced a continuous analog output proportional to the combination of chin displacement and force. This signal was digitized at a rate of 100 samples per second and stored through a computer based measurement system. There was no prior conditioning of the subject other than a 15 second trial to become familiar with the feel of the transducer and adjustment of their posture. All subjects performed approximately 15 seconds of motion in two rotational manners (clockwise/counterclockwise). Each subject was tested on the two transducers which varied in stiffness. The longer transducer had a vertical and lateral stiffness of 0.128 and 0.165 N/mm respectively while the shorter device had vertical and lateral stiffness of 0.443 and 0.532 N/mm.

## RESULTS:

The data obtained from the test subjects can be converted to illustrate either the variation of the displacements of or force exerted on the chin activated transducers. Figure 2.) illustrates a typical test variation of the lateral and vertical displacements that were "comfortable" motions for one of the subjects used in these trials. In this test a boundary can be established which potentially defines the range of motions that were within the capability of this subject. The force exerted on the transducer is linearly related to the displacement at the end of the transducer by the stiffness of the device. Thus, similar data reduction and presentations can be obtained for the force exerted by the subject which resulted in the range of motions illustrated in Figure 2.).

For this trial study the results indicate that with the less stiff transducer comfortable motions ranged from 10.3 mm in the lateral direction to 12.7 mm in the vertical direction with accompanying force inputs of 1.5 to 1.7 N in the above mentioned directions. With the stiffer transducer the range of motion decreased significantly to 5.7 mm and 6.4 mm in the lateral and vertical direction with the range of input force remaining at or slightly higher than those obtained with the less stiff transducer.

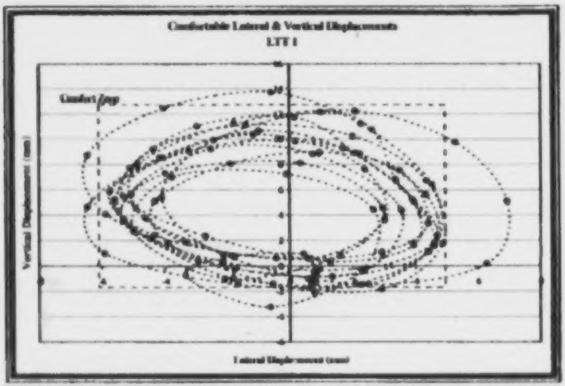

**Figure 2.) Typical Variation of Vertical and Lateral Head Motion with "Joystick" Transducer**

## DISCUSSION:

Conclusions are not appropriately significant with the small sample size used in these trials but trends can be defined. Based on these preliminary results it appears that the force exerted to activate a physical control device can be one of the most significant design parameters to consider. For example, when comparing the motions obtained with the two transducers employed, nearly twice as much displacement was obtained with the less stiff transducer while the forces that accompanied this motion were significantly similar to that of the stiff measurement device. Though more extensive studies should be concluded it would appear that some initial design criteria can be obtained in the manner outlined in this study.

The measurement device and system employed in this study lend themselves well to being duplicated easily; and more compact and efficient configurations can be developed. This would allow field studies using individuals with severe disabilities and produce significant design data.

The results of this study produced only response to the "comfortable" range of motions, subsequent work should also address how control system stiffness impacts the accuracy, speed, etc., of user inputs.

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# THE EFFECTS OF TRUNK STIMULATION ON SEATED WORKSPACE

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## ABSTRACT

Electrical stimulation was applied to the lumbar trunk extensors in individuals with spinal cord injury (SCI) to determine its effect on seated workspace. The volume of reachable bimanual workspace, its orientation in space, and reach parameters (arm span and reach length) were measured for four subjects with longstanding SCI with and without trunk stimulation. The perceived benefit of stimulation was rated using an ordinal scale. Reachable workspace volumes shifted forward and arm span increased with stimulation, effectively increasing bimanual reach length. Subjects preferred using stimulation in most trials. The results are encouraging and can be a foundation for developing more advanced systems to control seated posture and balance.

## BACKGROUND

The muscles of the human trunk provide the chief means of achieving stability and balance of the head and torso. The erector spinae (ES) are the primary trunk extensor muscles, and the prime postural muscles used in maintaining an erect sitting position. The muscles receive segmental innervation from the dorsal rami of the spinal nerves along the length of the muscle. SCI results in paralysis of the ES muscles below the area of the injury and can diminish or eliminate voluntary trunk extension. SCI is accompanied by dramatic changes in seated posture, including posterior rotation of the pelvis against a backrest (1), and decrease in the range of active movement of the center of pressure (COP) (2). Individuals with low cervical and thoracic level SCI are often restricted to reaching unimanually because of a lack of trunk control to stabilize the body and maintain balance, and are at risk for pressure sore development and other complications due the unhealthy postures assumed after paralysis of the trunk musculature.

Electrical stimulation of the peripheral nerves can be applied when an individual with SCI has preserved excitability of lower motor neurons. The benefits of stimulating the ES during standing are currently being studied (3), but the effects of trunk stimulation on the seated subject have not yet been quantified, specifically, the effects of ES stimulation on bimanual reaching and holding tasks. If stimulation of the ES can stabilize the torso while seated, it might allow individuals increased use of their upper extremities in their workspace.

## RESEARCH QUESTIONS

The purpose of this study is to quantify the effects of electrical stimulation on the reachable workspace, or the range of locations where a person can position his/her arms, and the controllable workspace, or the range within which a person can perform a specified task (4). It is hypothesized that the reachable and controllable workspace will increase with stimulation. As well, it is hypothesized that subjects will prefer using trunk stimulation in bimanual reaching tasks when compared to the same activities without stimulation.

## METHODS

Four individuals with motor complete SCI participated in the study (3♂, 1♀; Ave age = 35.25yrs ± 9.22yrs; All subjects ≥ 3yrs post-injury). All subjects were implanted with intramuscular stimulating electrodes in the T11/L1 or L1/L1 spinal roots to activate the lumbar ES as a part of the CWRU/VA implanted standing neuroprosthesis (5). The positions of reflective markers placed on the acromions, bilateral ASIS and PSIS, and a custom manipulandum designed to keep the hands a fixed distance apart were monitored by a VICON 370 motion capture system.

Reachable workspace was determined by sweeping the handlebars through the extremes of the range of motion without losing balance while sitting without a backrest. Controllable workspace was determined by reaching forward maximally holding various masses (0lb, to 2.5lb, in 0.5lb increments) for 5 seconds while seated with a backrest, and then returning the masses to the lap. The reaches were performed at 2 targets. Target 1 was at head-level and Target 2 was at knee-level. Two parameters were measured – the arm span, or the average of the lengths of the segments from the acromion markers to the handlebar markers bilaterally, and the reach length, or the endpoint of the average of the right and left handlebar markers. The pelvic angle was calculated in both reachable (no backrest) and controllable (with backrest) workspace trials before and after stimulation. Trials were rated on the 7-point Usability Rating Scale (URS) to determine effort and subject preference (6).

## RESULTS

With stimulation, the volume of the reachable workspace either stayed the same (Subjects 2 and 4) or increased (Subjects 1 and 3). In all subjects, there was a forward and upward shift of the reachable workspace volume in the laboratory space. Figure 1 shows the shift in all subjects. Subjects 1, 2, and 4 experienced a forward shift in the reference point, which was calculated as the average of the acromion markers, over 4.5cm, and Subject 3 experienced an upward shift of over 5cm. Subjects 1, 2, and 3 experienced an anterior pelvis rotation over 20° with stimulation, and Subject 4 experienced an anterior rotation of over 7°.

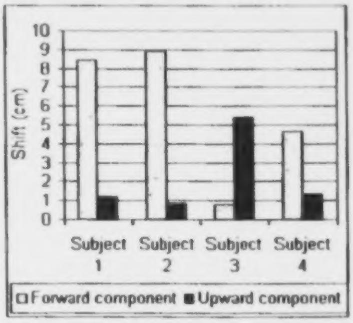

Fig. 1: Shift in reachable workspace

In the controllable workspace trials, there was a statistically significant increase in arm span with stimulation in all subjects. Figure 2 shows the change in arm span at Target 1 for Subject 3. There was no significant change in the reach length in subjects 1 and 4, and there was a decrease in the reach length in Subjects 2 and 3. All subjects experienced an anterior rotation of the pelvis with stimulation while using the backrest, however the amount of rotation was less than without the backrest. Subjects 2 and 3 experienced a rotation over 10°, and Subjects 1 and 4 experienced a rotation less than 3.5°. All subjects expressed a preference for stimulation in almost all trials. Subject 2 preferred performing the

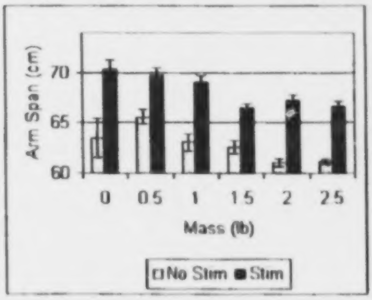

Fig. 2: Arm Span for Subject 3 (Target 2)

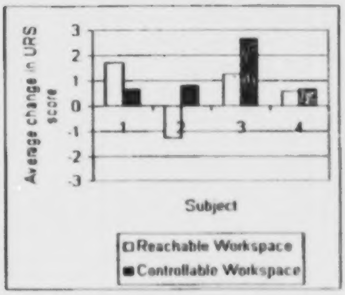

Fig. 3: Average change in URS scores

reachable workspace trials without stimulation. Figure 3 shows the average change in URS scores with stimulation.

## DISCUSSION

An increase in bimanual reach length can allow individuals with low cervical and thoracic SCI greater access to objects in their workspace bimanually, and can make a dramatic difference in work performance while seated at a desk, or any other seated workstation. The increase in arm span with stimulation supports the hypothesis; however, the decrease in reach length does not. The increase in arm span can allow these individuals to hold larger objects in front of the body in the sagittal plane as greater arm extension can be achieved with stimulation. The hypothesized preference for stimulation by the subjects was supported by the URS data. If electrical stimulation is to be applied functionally, there must be some reassurance that the consumers will prefer using it.

The results of this study are encouraging and can provide a basis upon which to build advanced clinical systems to allow individuals with low cervical and thoracic SCI increased access and control over their environments. For example, closed loop control systems can be explored to assist in maintaining balance and assuming stable postures away from the backrest by using input from sensors placed on the trunk to modulate the level and pattern of stimulation to the ES muscles.

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# Service Delivery & Public Policy
# (Topic 6)

# PERCEIVED RESPONSIBILITIES OF REHABILITATION PROFESSIONALS AND STAKEHOLDERS IN DISTANCE DELIVERY OF CONTINUING EDUCATION

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## ABSTRACT

This paper examines the results of surveys conducted with: (a) rehabilitation professionals in Alberta, and (b) stakeholders representing employers, professional associations and regional health authorities in the province. The purpose of the surveys was to examine the perceptions of the two groups on the degree of responsibilities in distance delivery of continuing education. The groups agreed that currently the responsibilities are shared, but in the future, they foresee personal responsibilities, including financial, to increase. This implies that while there are advantages for delivering continuing education at a distance, organizers should to be prepared to address the perception of increased personal responsibilities as this may itself be a barrier to accessing continuing education via distance delivery.

## BACKGROUND

Continuing education is necessary for maintaining professional competence and expertise (1). But who should be responsible for continuing education? Brocket and Bauer (1) advocate for a systems approach that involves collaboration between professionals, multidisciplinary team members and professional organizations. When continuing education is delivered at a distance using technologies, the collaboration between stakeholders becomes more elaborate. For example, it is desirable and more efficient to share telecommunication and videoconferencing technologies between academic institutions, regional health authorities and employers. Technologies also make it more feasible for continuing education content to be shared between academic institutions and clinical sites. However, the multiple uses of these technologies and their associated costs call for careful coordination, and may increase indirect costs to the learner.

In January 2000, the Alberta Rehabilitation Continuous Learning Network (ARCLN) was established to coordinate continuing education opportunities, at a distance, for rehabilitation professionals within the province of Alberta. Over an 18-month period, approximately 950 different learners in Alberta participated in continuing education sessions coordinated by ARCLN. Continuing education content was delivered using live broadcasts, or rebroadcasts via satellite; videotapes of these broadcasts, clinical case presentations and research seminars via videoconferencing, and web-based technology.

For the purpose of this study, "rehabilitation professionals" were members of one of the three rehabilitation professional associations in Alberta (AAROT, APA, SHAA), and "stakeholders" were defined as representatives of academic institutions that train a health professionals who may work in rehabilitation, rehabilitation professional associations or colleges, employers and regional rehabilitation directors or other representatives of regional health authorities.

## RESEARCH QUESTION

What are rehabilitation professionals' and stakeholders' perceptions of each other's responsibilities in accessing continuing education delivered at a distance? What are the implications for distance delivery of continuing education created for rehabilitation professionals?

## METHOD

Two separate surveys were distributed by mail in early 2001. The first survey, The Health Professional Survey was distributed using a systematic random sampling to 1050 health professionals who were members of one of the three provincial rehabilitation professional associations. The Stakeholders Survey was sent to 74 members of professional organizations, academic institutions, employers and regional rehabilitation directors. These surveys were sent out 1 year after the implementation of ARCLN. Both surveys contained question items that pertained to their knowledge of and experience with the continuing educations sessions offered through ARCLN, and their perceptions of the roles and responsibilities of the two groups in meeting continuing education needs.

## RESULTS

A total of 350 health professionals responded (33% response rate), and 37 stakeholders responded (50% response rate) to the surveys. Table 1 summarizes how the two groups of respondents viewed who is currently responsible for continuing education. The majority of respondents, between 60 and 70%, in both groups perceived that the current responsibilities are shared between professionals and stakeholders, although this proportion is higher in the stakeholder group. Almost 20% of the respondents in both groups thought that current responsibilities rest with individual practitioners.

**Table 1**

| Current Responsibility for Continuing Education | % Stakeholder (n=36) | % Health Professional (n=340) |
|---|---|---|
| Mostly with the RHA | 11.1 | 5.9 |
| Shared between both | 69.4 | 60.3 |
| Mostly with the individual | 19.4 | 19.1 |
| Other Responses | | 14.7 |

Table 2 describes how the two groups perceived these responsibilities to change in the future. In both groups, slightly over a third of the respondents did not think that responsibilities will shift in the future. Over 40% of respondents in each group agreed that individual responsibilities will increase. In contrast, about 20-25% of the respondents believed that responsibilities will increase for employers. The survey did not specify what these responsibilities were. However, health professionals were asked whether they "expect to have to personally pay for continuing education in the future". Over 85% of these respondents (n=332) stated "yes". Further, when the health professionals were asked about the "extent of personal responsibility to regularly take continuing education courses regardless if there is a cost", 78% (n=347) stated that this would be a "big" or "very big" responsibility.

**Table 2**

| Changes in Responsibility for Continuing Education in the Future | % Stakeholder (n=36) | % Health Professional (n=330) |
|---|---|---|
| Great increase in individual responsibility | 19.4 | 23.0 |
| Some increase in individual responsibility | 22.2 | 22.4 |
| No change | 33.3 | 35.5 |
| Some increase in employer responsibility | 13.9 | 12.4 |
| Great increase in employer responsibility | 11.1 | 6.7 |

## DISCUSSION

The results of this study show a fairly consistent view about continuing education with both stakeholders and health professionals studied. Currently the responsibility is viewed as being shared between the employer and employee and many think that the responsibility on the employee will increase in the future. There was agreement by health professionals that they need to take considerable responsibility, including financial, in their continuing education. These results are consistent with the trends of distance delivery of continuing education, which allow additional options and flexibility (2). Careful documentation is needed to identify if, in fact, professionals are assuming more personal responsibilities for pursuing continuing education, what are these responsibilities. If these include financial, are they direct or indirect, and are they realistic? The stakeholders, including employers and professional associations, should examine and describe their roles and responsibilities in making continuing education meaningful and feasible for the ongoing professional development of their members.

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## ACKNOWLEDGMENTS

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# INTEGRATION OF AT EDUCATION BY REHABILITATION PROFESSIONALS

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## ABSTRACT

Distance learning, particularly in the area of assistive technology (AT), is gaining momentum within higher education (1). Evaluations from a web-based graduate course, *Applications of Rehabilitation Technology*, indicated that the course information, interaction, and activities were practical and effective for rehabilitation professionals. A survey was conducted to determine if these professionals continued to use the resources and strategies offered in the course and if they were more likely to recommend assistive technology or consult with AT specialists since completing the course. Results indicate that a high percentage of these professionals have integrated AT information into their work routine one to three years after completion of the course.

## BACKGROUND

Internet-based instruction provides access twenty-four hours a day, expanding educational opportunities to those who cannot easily access traditional education due to geographical location, time constraints, family responsibilities, or other individual access issues. As colleges and universities increase their offerings in online courses and degrees, research is focusing on aspects beyond the comparison to traditional on-campus learning (2, 3). Issues include if and how course competencies are met and more importantly, if and how the information is applied in the professionals' job responsibilities after completion of the course.

The graduate course in this study is required for a Master of Science degree in Rehabilitation Counseling. The online version of the 3-unit course was designed for rehabilitation counselors currently employed by state departments of rehabilitation who were earning their degrees as required by the Comprehensive System of Personnel Development (Section 101(a)(7) of the Rehabilitation Act Amendments of 1992). The 12-week course included online discussions and activities related to the legislative and historical context of AT, assessment strategies, universal design, and other areas of AT (e.g., computer access, augmentative/alternative communication, job accommodations, adaptations for daily living). Materials, resources, and information were shared via audiotapes, videotapes, and a variety of online instructional strategies that facilitated interaction between students and instructors as well as among students. Online discussion boards, email, listservs, and links to other websites, weblectures, slide presentations, and articles provided information in accessible formats for all students, including about 15% who reported having disabilities.

The online course is typically taught once a year. The first course in 1997 enrolled rehabilitation professionals from one state, with subsequent courses including students from 18 states. Instructional facilitators who were AT content area experts provided small-group instruction and "virtual" guest lecturers presented information with follow-up discussions on specific topic areas.

## RESEARCH QUESTION

Course evaluations provided immediate reaction from students when they completed the course. Those submitted anonymously by the students following each session of this distance course were overwhelmingly positive. However, it was unclear as to the impact that this new knowledge had on their performance as rehabilitation counselors. The questions for the study focused on the impact after a period of 1-3 years since course completion, including: 1) How, if at all, are the information and resources being integrated in the professional responsibilities of the students? and 2) Is there a relationship between having more knowledge about AT and their use of AT services and resources? Inquiries were also made regarding their pursuit of further training in the AT area.

## METHOD

The survey consisted of 10 statements to be rated according to a Likert–type format. Questions were designed to measure if and how the respondents were integrating the use of AT resources from the course, including: recommending AT devices to their consumers; referring consumers for AT services; consulting with AT service providers; sharing AT information with their colleagues; using strategies learned in the course; and rating their perceived comfort level with AT. The respondents were asked to rate the practice described as to whether they had increased, decreased, or stayed the same since they had completed the online course. The final two questions asked if they had taken additional AT training and if they were interested in participating in more training.

Given that the course was offered via distance, the survey was administered in a similar fashion. The survey was sent to the class listservs from each of the student cohorts as an email attachment, accompanied by an introductory letter from the survey author, who was not the instructor. Directions for replying to the survey were included, as well as assurance that their answers would remain anonymous (i.e., the attachment with the completed survey did not include the name or email address of the sender). Respondents also had the option of faxing or mailing the completed survey. A total of 130 surveys were sent, with follow-up requests issued one week and two weeks later.

## RESULTS

Of the 130 surveys transmitted, 28 were "automatically returned" (i.e., computer generated response) indicating that message could not be delivered. Of the remaining 102, 71.5% were completed and returned by respondents (N= 73). Students who had completed the course most recently were more likely to return the survey (43%); however, there was not a significant difference in the ratings between cohorts as noted by cross-tabulations. Overall, the answers indicated that these rehabilitation professionals had increased the frequency of their professional practices related to assisitive technology in all areas, including: recommendations for AT devices (74%); referrals for AT services (68.5%); consultations with AT experts or providers (57.5%); provision of AT resources to colleagues (63%); use of person-centered approach to assessment (72.6%); and use of online resources (74%). A much smaller percentage reported that these practices stayed the same, and none indicated that their practices had decreased, except in one case. When asked to rate their comfort level with recommending AT to their consumers, 87.7% indicated an increase. While 79.5% indicated an interest in attending more training in the uses of AT, only 16.4% had taken any.

Cross-tabulations were run to determine the correlation between the increase in their practices and their comfort level in recommending AT. As might be expected, the correlation was high. For example, 80.6% and 78% of those who reported an increase in recommending AT devices and referring individuals for AT services respectively, indicated that their comfort level had also increased. Other practices fared similarly, except for the cross-tabulation between comfort level and consulting with AT experts or service providers, which will be discussed below.

## DISCUSSION

Individual student comments and post-course evaluation surveys highlighted the practicality and usefulness of the course, but as with any course, there is no guarantee that students would integrate information into their work repertoire. The follow-up survey results indicate that, at least from their own perceptions, rehabilitation counselors have integrated AT information, strategies, and resources into their work routines. Further investigation should be done in order to determine if these perceptions can be documented by the numbers of consumers acquiring AT devices and/or receiving AT services. In addition, more inquiry should be made on training needs and availability.

A note should be added regarding the consultation with AT experts. The question was written with the assumption that using more AT expertise was a desirable outcome. However, based on a number of comments submitted during a subsequent course, consulting less with outside experts may have indicated that the individual's own skills increased. In several cases, the professional reported increased confidence in completing more of the process with the consumer, reserving the use of AT expertise for complex issues. Following up on this aspect would provide important information as to the impact of this type of education on AT service delivery in the rehabilitation process.

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# ONLINE RESOURCE FOR TEACHING UNIVERSAL DESIGN

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## ABSTRACT

The authors are developing an interactive Internet web site of universal design instructional materials, project ideas, visuals, teaching strategies and resources for use by a range of educators, students, practicing designers and individual user/experts. The web site will allow great flexibility in how the projects, visuals and instructional materials are used. An online journal and discussion forum will support educators. This collection will promote an infusion model of teaching rather than a prescriptive curriculum approach. The web site will internationally draw from and be promoted to faculty, practitioners, and others interested in universal design education.

## BACKGROUND

Universal design is a concept that recognizes, respects, values and attempts to accommodate the broadest possible spectrum of human ability in the design of all products, environments, and communications.

The Universal Design Education Project (UDEP) was conceived by Elaine Ostroff in 1989 as a vehicle for making the simple concepts of universal design an integral component of design education. UDEP supported faculty to develop new teaching strategies for infusing universal design values into the culture of their schools, values that would help inform the creation of a new ethic of design education and practice that acknowledges and celebrates human diversity. Over its duration, UDEP grew to include stipends for faculty at over 30 schools of design, forums for scholarly discussion, and a book published in 1995 (1). Since that time, UDEP has expanded to include additional faculty in the United States, Canada, Europe and Asia.

The need for additional and more sophisticated universal design educational materials grows each year and along with it, the challenge of widespread dissemination.

## STATEMENT OF THE PROBLEM

This web site is intended to support the teaching and study of universal design and to provide a place where educators can interact with each other. The site is designed for use by faculty members, students (of any age and stage), and user/experts. The site supports professional design education as well as continuing education and the teaching of children in kindergarten through grade twelve (U.S.).

## DESIGN

This project is being conducted collaboratively by the Center for Universal Design in the College of Design at North Carolina State University, Elaine Ostroff of the Global Universal Design Education Network, and the School of Architecture and Planning at the State University of New York at Buffalo.

The Internet web site being developed in this project features a variety of materials for a range of disciplines, levels, and interests including: instructional materials such as syllabi, course modules, sample assignments, and evaluation methods; content resources such as computer animations and renderings of excellent examples of universal design; full text of classic universal design writings; an annotated bibliography of other available materials; and links to relevant resources. The interactive site also provides online support for educators including a discussion forum, an online journal, a listing of universal design programs and courses offered worldwide, as well as a calendar of events both upcoming and archived.

The project team published an ongoing call for submission of educational materials for the site. All entries are reviewed by a team of project staff and advisors to ensure suitability for publication prior to posting. If accepted, these are posted in the "Educational Resources" section of the site.

The project's Internet Web site is titled "UD Education Online" and its online address is <http://www.udeducation.org>. The site's home page contains links to the following pages:

- What's New? *Find out what new additions have come to UD Education Online.*
- About UD Education Online: *Get more information about what UD Education Online is all about.*
- Educational Resources: *A comprehensive source for educators who are looking to include universal design in their curricula.*
- How to Submit Materials: *Find out how to submit materials to UD Education Online.*
- Frequently Asked Questions (FAQ)
- Educators' Forum: *Login to UD Education Online to participate in discussions on current topics related to UD.*
- Feedback
- Search

On the Internet, the project has two sites: a pilot site and a working site. The pilot site can be viewed on the Internet by the general public, while the working site is in a private location so that ideas can be developed and reviewed internally before they are moved to the public site.

Because maximum accessibility and usability are essential to the project, the site is W3C Level Triple A Compliant. Among other characteristics, every photographic image or other graphic element on the site is accompanied by an alt tag, a caption, and a full text description.

## EVALUATION

A group of six educators with experience in universal design and from a range of design disciplines are serving as advisors to the project. They are:

- Polly Welch, Architecture, University of Oregon
- Robin Moore, Landscape Architecture, North Carolina State University
- Louise Jones, Interior Design, Eastern Michigan University
- Meredith Davis, Graphic Design, North Carolina State University
- Gregg Vanderheiden, Industrial Engineering, University of Wisconsin at Madison

In addition, Jim Allman, a computer programmer who worked with the Center for Universal Design on developing and ensuring the maximum accessibility of its *Universal Design Exemplars* CD-ROM (2), has been serving as an external technical consultant to this project. This group reviews materials and participates in conference calls, reviews the Web site as it is developed, and submits feedback to the team by phone, e-mail, and through online forms. The project team has also enlisted the involvement of a small group of individuals with disabilities who are evaluating the site to ensure that it is accessible to and usable by them.

## DISCUSSION

As this paper is being written, the first fully configured version of the project web site has just been launched. The previous version of the site contained only a call for submission of educational materials for possible inclusion on the site, which was restructured into the "How to Submit Materials" section of the full site. At the beginning of the project, submissions were invited from specific educators whom staff knew had interesting and valuable materials to share, and most responded favorably. Voluntary submissions from educators unknown to the project team have been few to date but more are expected as the site is populated with a rich variety of good materials and word spreads about the value of the site to the educational process.

The project team is striving to make the site as valuable as possible for everyone involved. To this end, several issues have arisen and solutions found.

First, in order to enhance the results of searching the site for specific content, every author must complete a cover sheet to accompany each submission. This sheet contains basic information about the submission, as appropriate: e.g., keywords, educational level for which the submission was created, duration of course or exercise, etc. The data from this form flows automatically into a database that can be searched by the same fields.

Second, the project team is sensitive to concerns about copyrights. All authors will be asked who holds the copyright to each submission; this information will be included with all materials on the site. In order to gain access to the copyrighted materials, site visitors will be required to enter basic contact data about themselves and promise to give a full citation for any of the online materials that they use, with or without copyright, and give feedback to the author(s).

Third, the interactive features of the web site are vitally important to the project investigators. Site visitors will be encouraged to write feedback to the authors and this will be visible on the site, together with the materials, for the benefit of other visitors. There will also be an Educator's Forum that will provide an ongoing opportunity for discussion on various themes and issues.

The authors hope that by providing this extensive and rich collection of educational materials online, they will facilitate the instruction and study of universal design. They hope to encourage the inclusion of universal design subject matter in a wide variety of existing courses and the creation of new courses on the topic.

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# A COMPARISON OF ASSISTIVE TECHNOLOGY EXPERTISE ACROSS URBAN, SUBURBAN AND RURAL WISCONSIN SCHOOL DISTRICTS

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## ABSTRACT

The reauthorization of IDEA in 1997 created an unstated mandate that all professionals working with students with disabilities, regardless of location, have a working knowledge of assistive technology devices and service delivery strategies. This study analyses the difference in assistive technology expertise across school personnel in Wisconsin's urban, suburban and rural public school districts. Specific statistical analyses reveal that there is a significant difference in expertise across groups, suggesting systems change for rural professionals, administrators and the institutions of higher learning that prepare them for providing best practices.

## BACKGROUND

The reauthorization of the Individuals with Disabilities Education Act (IDEA) in 1997, requiring that all IEP team participants have at lease a general working knowledge of assistive technology, has left many educational professionals struggling with the process of AT consideration and determination. A daunting task for many professionals in special education, this demand for AT expertise may be particularly overwhelming for educators working in rural settings who often lack the immediate support, training, funding and resources needed to make appropriate assistive technology decisions.

To date, few programs are in place to create technology specialists within special education, much less programs to create assistive technology specialists at a bachelors or masters level. Hence, practicing educators who feel the frustrations of complex and difficult to learn technologies, limited time to explore technology, limited administrative support, and professional isolation, struggle to provide appropriate instructional services to their technology users and often do not have the necessary knowledge to make informed decisions as a part of a technology team (1), (2), (3). Indeed, a survey study of special educators completed by the Department of Special Education at Illinois State University (ISU) found that over 1/3 of teachers polled indicated that they lack basic competence in assistive technology (4).

Rural communities face additional challenges with the delivery of assistive technology services. Distance, location, and access to specialists in the field of assistive technology are areas of concern for rural teachers and therapists (5). Unlike some urban school districts, which are able to develop their own equipment lending libraries, rural districts are faced with a lack of financial resources to set up such a system for their individual district (1). Teachers and therapists lack the professional support and access to continuing education as compared to their urban counterparts, potentially reducing the capabilities of these individuals to provide quality assistive technology services within their rural districts.

# AT EXPERTISE

## RESEARCH QUESTION

Ever-increasing and advancing technologies demand that professionals working with individuals with disabilities in America's public schools have an adequate knowledge of appropriate assistive technology devices and services. Challenges facing educational teams are felt across all settings, but rural districts face unique challenges when attempting to adequately train staff and provide appropriate AT services to students with disabilities. This study seeks to answer the question: Is there a difference in assistive technology expertise among educational professionals in urban and rural areas of Wisconsin?

## METHOD

The method used for collecting data for this study was a structured, tri-leveled questionnaire survey. The development of this survey involved multiple stages stemming from the research question and leading to the development of three separate instruments. One of the three instruments, the assistive technology content questionnaire, a 25-question multiple-choice questionnaire addressing content areas pertinent to school professionals, underwent multiple revisions and analyses and was created specifically to address the posed hypothesis.

A tiered distribution methodology, consisting of directors of special education for each district, the one individual in each district who demonstrates the most AT expertise, and other individuals displaying AT knowledge, was utilized to accurately identify the targeted population of professionals utilizing assistive technology in their practice in Wisconsin's public schools. This targeted population was classified according to the Wisconsin Department of Public Instruction Library and Statistical Information Center's rurality index. This classification scheme was used to statistically compare the scores obtained on the AT content questionnaire with respect to rurality using a one-way analysis of variance and a specific independent t-test.

## RESULTS

The level of AT expertise of 197 Wisconsin professionals was analyzed using a one-way analysis of variance (significance level of 0.05) and a specific t-test comparing urban and rural personnel (adjusted significance level of 0.0125). The results of the ANOVA indicated significant findings of p = 0.0338 and the results of the t-test revealed nearly significant findings (p = 0.018).

Table 1

Output Summary Table One-way Analysis of Variance: Effect of Urban, Suburban of Rural Classification on Overall Score on AT Content Questionnaire

| Variance | SS | df | MS | F-ratio | p-value |
|---|---|---|---|---|---|
| Between Groups | 46.322 | 2 | 23.161 | 3.4471 | 0.0338 |
| Within Groups | 1303.5 | 194 | 6.7191 | | |
| Total | 1349.82 | 196 | | | |

Note:
- p < 0.05; SS = Sum-of-Squares; df = Degrees of Freedom; MS = Mean-Square

Table 2

Output Summary Table for t-test Comparison of Urban and Rural Groups

| Group | n | mean | std. dev. |
|---|---|---|---|
| Urban | 34 | 20.735 | 2.064 |
| Rural | 108 | 19.546 | 2.652 |

| t-test | t | df | p |
|---|---|---|---|
| Equal Variances | 2.393 | 140 | 0.018 |
| Unequal Variances | 2.724 | 70.4 | 0.008 |

Note:
- adjusted p < 0.0125

## DISCUSSION

Multiple layers of importance surface from these observed significant statistical differences. Practitioners in rural areas need to realize that they may be statistically at a disadvantage compared to urban professionals in regard to important AT knowledge and actively pursue administrative support for continuing education. Likewise, administrators must be proactive in educating their staff and make considerable efforts to have on-going, continual education to increase the knowledge and confidence levels of staff in order to determine and apply the most appropriate assistive technology. Lastly, institutions of higher learning, many of which are frequently housed in urban settings, must seek to provide innovative and creative modes of education and actively seek to provide collegial support for professionals practicing in less populated and more remote regions of the state.

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# ACCESSIBLE TELECOMMUNICATIONS INFORMATION FOR PEOPLE WITH COMMUNICATION IMPAIRMENT

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## ABSTRACT

Information on communications equipment and services is available but its accessibility for people with communication impairment is questionable. The diversity of text-based and audio-visual formats and of venues or personal means of disseminating information has led to an investigation of the information needs and preferences of this group. Sixty five survey respondents used a variety of information formats but preferred to have contact with therapists and carers, family and friends, and disability agencies. They also preferred information to come to their home and relied less on information provided at community venues and through the Internet.

## BACKGROUND

Information is the communication of facts and knowledge. When people have information they can make informed decisions about their life activities and their relationships with others. Information is required for people with disabilities to make decisions that affect their lives. Having information that is accessible is critical. In a paper delivered at the 1993 National Disability Information Project Conference in the U.K., Hasler (1993) asserted that lack of information is disabling.

Many people who have a communication impairment have particular information needs. They may have literacy difficulties so find reading hard-copy and web-based information difficult. They may have difficulty speaking or may not speak so cannot easily ask for information. They may use communication symbols and electronic communication aids which do not have a full range of vocabulary for asking questions. These information consumers may also have cognitive difficulties, sensory, and physical/dexterity difficulties which provide further access challenges. When information is not available or is not presented in accessible ways, these consumers are particularly disadvantaged in their use of telecommunication equipment, services, and carrier options.

People in the community use a multitude of formats for acquiring information. Numerous hard copy forms exist such as brochures, reports, newspapers, magazines, information flyers, and phone books. Audiotape, video, television, the Internet, and large print and braille formats are also used. Ideally, information is written clearly in Plain English or conforms to W3C guidelines for accessible document development. Information is also shared by family and friends (Williamson, 1993; Gillard, 1997) and is provided at a variety of venues (agencies, retail shops, through carriers, the Internet). Many people make requests for information over the telephone. Are these formats and venues accessible to people with communication impairment? Little research has been completed which clarifies the needs of this consumer group.
ACCESS INFO.

## RESEARCH QUESTION

One objective of this study was to investigate the telecommunication information needs and preferences of people with communication impairment in Australia. An additional objective was to develop guidelines for the development of accessible information for this group.

## METHOD

In this paper, preliminary results from respondents with communication impairment are reported. Participants were informed about the project through flyers, letters, email, disability agency contacts, and on web sites and listserves. A survey with forced choice, and closed and open-ended items was written using Plain English standards. A requested hard-copy survey format (larger font and 1.5 line spacing) was used to facilitate completion by people with a communication impairment, either independently or with the help of a support person. Sixty five participants aged 18 and over from Victoria, Tasmania, South Australia and Queensland completed the survey. Quantitative data was analysed descriptively using SPSS. Open-ended responses were analysed using inductive thematic analysis.

## RESULTS

The primary sources of information on telecommunications technology and services that respondents used were: disability agencies (50%), television (40%), the phone book (39%), radio (34%), agency newsletters (32%), and brochures (31%). Lesser used sources were: newer carriers (2-5%), citizen advice bureaus (9%), local libraries (12%) and the Internet (20%). When questioned about the importance of different formats and strategies for generic information purposes, 96% of respondents indicated that getting information from a therapist or carer was 'very important' or 'important.' Chatting to friends and family (89%), getting information from newletters (86%) and from television (86%), and from reading newspapers, magazines, and brochures (79%) were also important means of acquiring information. The 'least important' sources were audiotape (60%), the web (50%), and information found in the community (40%). Visual supports were felt to be important for people with a communication impairment. Three quarters of respondents said that photos were 'very important' while two thirds of respondents said that line drawing/pictures and communication symbols were 'very important.'

Difficulties with language and complexity, the need to turn pages, and/or size of print were noted as significant information access issues. Poor literacy, the impact of other impairments, poor responses from others, poor physical access in the community, not having the time to access information, and not knowing what to ask were additional challenges. Respondents called for better access and adoption of these format characteristics:

- Make information clear and easy to read and understand; reduce complexity
- Use larger print (14 or 16 font)
- Highlight the key points
- Use dot points
- Use visual information such as photos and communication symbols

ACCESS INFO.

- Provide a range of oral/audio and visual formats for information

Information also needs to be provided on accessible web sites and for people living in non-metropolitan areas. Human involvement in information was highlighted in some respondents' requests for personal assistance to go through information and turn pages. Although a range of formats, including the Internet, was requested, there was a preference for mailed information to be sent to people's homes. Reliance on disability services and day settings for providing information were also clearly indicated by people's comments.

## DISCUSSION

People with communication impairment are a very diverse group. Some require no changes to the ways information is presented while others are heavily reliant on visual information and on others to explain new information to them. The need for human contact and assistance supports the findings of Williamson (1993) and Gillard (1997) that people rely on each other for information. The accessibility characteristics requested by respondents have ramifications for the development of text- and web-based formats and for the development of inclusive design guidelines. Requests for alternate formats reinforces the need for these to be provided routinely by government and by telecommunication equipment and service providers. People's reliance on others, particularly therapists and carers, and on disability agencies and services is important to consider in regard to staff time and work requirements and to employer expectations. People's specific requirements in the use of colour, headings, and logos, amount of and layout of visual information (including communication symbols), and amount of text-based information requires further investigation.

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# PROBLEM-BASED LEARNING FOR ASSISTIVE TECHNOLOGY EDUCATION II

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## ABSTRACT

This paper presents a problem-based learning approach used successfully to teach appropriate matching of basic electronic aids to daily living with consumers—one aspect of assistive technology content—to preservice students in a professional training program. This problem-based learning strategy can be replicated for any student learning the fundamentals of basic electronic aids to daily living.

## BACKGROUND

While many professional preservice training programs are predicated primarily on traditional teacher-centered educational approaches, graduates sometimes demonstrate difficulty in generalizing their knowledge to real world contexts. To develop entry-level practitioners with strong abilities in the areas of critical thinking, problem-solving, communication, teamwork, self-direction, and lifelong learning, many medical schools have adopted problem-based learning, an educational strategy that places emphasis on the learner.

Problem-based learning, according to Barrows as cited in (1), is comprised of the following characteristics: learning is student centered, learning occurs in small groups, teachers are facilitators or guides, problems form the organizing focus and stimulus for learning, problems are a vehicle for the development of problem-solving skills, and new information is acquired through self-directed learning. Harden and Davis (2) categorize educational approaches according to an 11-step teaching-learning continuum that begins with traditional information-based, teacher-centered learning (no problem-based learning) and progresses toward increasingly more student-centered, problem-based learning tied to real situations. This continuum includes (a) theoretical (e.g., traditional lecture, textbook), (b) problem-oriented (e.g., lecture with protocols or guidelines), (c) problem-assisted (e.g., lecture followed by practical experience), (d) problem-solving (e.g., case discussions), (e) problem-focused (e.g., lecture with study guides), (f) problem-based: mixed (e.g., students opt for either information-based or problem-based learning), (g) problem-initiated (e.g., problems are used to interest students in a topic), (h) problem-centered (e.g., text provides a series of problems followed with information to solve problems), (i) problem-centered discovery (e.g., principles are derived by students from their work), (j) problem-based (e.g., information from one problem is generalized to another), and (k) task-based (e.g., problems are solved in real time in the clinical setting).

## OBJECTIVE

The objective was to categorize the existing method of teaching basic electronic aids to daily living fundamentals to preservice students in a professional training program at a Midwestern university and to determine a more effective educational approach.

## APPROACH

At this university, the existing primary method of providing fundamentals of basic electronic aids to daily living was categorized as a theoretical approach at the traditional, instructor-centered end of the teaching-learning continuum. The basic electronic aids to daily living fundamentals educational unit was redesigned, utilizing a problem-based learning strategy, similar to that which had already proved successful in teaching Windows accessibility features to preservice students in this same professional training program (3).

## RESULTS

In keeping with problem-based learning, the case study ("problem") is presented before content, providing structure for learning and allowing students to construct their own knowledge. In this redesigned educational approach, students worked collaboratively in groups to assemble an assistive technology solution for each problem from the program's battery-operated devices (robot, dinosaur, pig, elephant, swirl art machine, jungle toy, spaceship, and elephant), electrically-operated devices (lamp, fan, television, and radio), interfaces (battery interrupters and electrical systems), mounting devices, and various switches. The following is the redesigned educational strategy for teaching fundamentals of basic electronic aids to daily living.

Your team is consulting with a school district that wants you to incorporate assistive technology into everyday classroom activities. You are scheduled to see six students: four children (Chip, Katie, Rosanna, and Clark) in the early childhood classroom and two teenagers (Roscoe and Lorna) in the high school. As a team, determine an assistive technology solution, address positioning factors, and provide justifications for all aspects. (Please note: Following each problem are the solution and positioning factors in parentheses.)

Chip, a 4-year old boy with a diagnosis of cerebral palsy resulting in spastic quadriparesis, loves everything connected with the sky: airplanes, jets, rocket ships. He hates spending 30 minutes per day in the classroom prone-stander and shows little consistent fine manipulation skills. Chip, however, can bat at a balloon and move his left hand to a table slowly. (Position Chip in the prone-stander with the switch interfaced by a battery interrupter to the starship and placed in various positions to his left—both on the table and above.)

Katie, a 3-year old girl who was born without hands, giggles so much each time a certain Muppet character is around, her nickname is *Miss Piggy*. At school she is working on maintaining the extra range of motion in her hips to allow her to accomplish activities of daily living using her toes. Find Katie a playtime activity. (Have Katie sit independently to activate with each foot a switch, which is interfaced by a battery interrupter to the pig toy and positioned increasingly higher and closer to her face.)

Rosanna, a 5-year old girl with spinal muscular atrophy, is really into wild animals; she wears a leopard print one day, tiger the next. At school she has good and bad days. She can move against gravity on good days, but needs gravity-eliminated activities for difficult days. (Use a switch interfaced to the jungle toy by a battery interrupter for both days. Position Rosanna on good days in supported sitting with the switch placed in various locations above her current hand placement and on bad days in the sidelyer with the switch places for sideways—not up—activations.)

Clark, a 6-year old boy with a diagnosis of cerebral palsy resulting in spastic quadriplegia, smiles and babbles at "artificial life forms" such as the R2D2 character in *Star Wars* movies. His primary classroom goal is improving head control. (Place Clark in supported sitting with a mercury switch—

placed in a hat on his head and adjusted to activate with head verticality—interfaced with a battery interrupter to the robot toy.)

Roscoe, a 14-year old with a diagnosis of Duchenne muscular dystrophy, can no longer move against gravity. He spends 45 minutes after lunch in the classroom sidelyer, lives for the soap operas he is allowed to watch during that time, and wants to be more independent. (Place Roscoe in a sidelyer with a switch, placed for sideways activation and interfaced to a television by an electrical system. Position the TV on its side to match Roscoe's eye position.)

Lorna, a 15-year old with a diagnosis of cerebral palsy, always complains she is hot. She has difficulty maintaining trunk balance, keeping her head up, and stabilizing her limbs for purposeful activity. Lorna's speech is readily understandable by others and she is used to ordering people around. (Position Lorna in supported sitting with a mercury switch—worn as a pin on her chest and adjusted to activate with trunk verticality—interfaced to a fan with the electrical system.)

## DISCUSSION

The redesigned educational strategy for basic electronic aids to daily living fundamentals falls toward the problem-based learning end of the teaching-learning continuum. Compared with the initial teaching approach, this new educational approach for basic electronic aids to daily living fundamentals moved 8 rankings along the 11-step continuum to problem-centered discovery.

Problem-based learning, according to Edens (1), provides students opportunities to make a direct link between theory and practice—between "knowing that" and "knowing how"—to apply knowledge to problems they are likely to encounter in their professional careers. In a professional training program at a Midwestern university, problem-based learning became a more effective approach of providing fundamentals of basic electronic aids to daily living to preservice students.

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# PATHS TO MARKET

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## ABSTRACT

This paper reviews three different paths to market for new products as identified by the RERC on Technology Transfer. These three paths: 1) Standard Licensing; 2) E-Commerce; 3) Market Cultivation, are each most appropriate for different sets of circumstances.

## BACKGROUND

The Rehabilitation Engineering Research Center on Technology Transfer ($T^2$RERC) advances the methods of technology transfer through research, transforms technologies into products through development and facilitates the commercialization of new and improved assistive technology devices. The $T^2$RERC is a partnership of technical, marketing and consumer agencies experienced in assistive technology evaluation, transfer and commercialization. The Supply Push technology transfer program works to commercial prototype inventions with market potential. (1)

## APPROACH

The $T^2$RERC's Supply Push program runs an exhaustive series of evaluations on any devices accepted for review from qualified sources. These evaluations approve only new and unique inventions that demonstrate technical feasibility, market potential, and consumer acceptance. (2) The evaluations are combined into a Commercialization Package containing technical, marketing and consumer data. The Commercialization Package is then presented to relevant corporations so they can assess the device's potential as a new product. (3)

We work with devices that address both broad and narrow markets, and with products that are independent or function within a suite of products. We have discovered that these differences require different approaches to successful commercialization. At present, our work has revealed three approaches – or paths to market: 1) Standard Licensing; 2) an E- Commerce; and 3) Market Cultivation. Based on the potential market size, and the potential barriers in the path to that the technology faces, one of these three alternative paths may be the most appropriate path to follow.

*Path 1: Standard Licensing*

This is the conventional approach to bring a product to the marketplace. The Commercialization Package is presented to companies in the device's target industry sector. As with all new technologies or devices, there is a limited window of opportunity for companies to sell a new product to their customers. Beyond that window, other more attractive products will be introduced and sold. Therefore, the Commercialization Package is treated as a time sensitive document, developed and offered to the potential licensee as quickly as possible.

The timing must also coincide with the targeted company's product development cycles. For example, a company in the wheeled mobility sector may have its product development cycle revolve around the major industry tradeshow (i.e., Medtrade) where new mobility products are introduced and orders for these products are first obtained from attendees. These companies are only receptive to new product opportunities immediately after the tradeshow (December-January). Approaching a company outside of their cycle guarantees that it will not be reviewed until the next product cycle, which likely means the product will miss its window of opportunity. Further, providing incomplete information in the Commercialization Package will result in missing the window, because the time required to gather and furnish the additional information will push it beyond the product development cycle. Timing is the critical success factor in the Standard Licensing path to market. The Kinetic Seating System is a recent example. (4)

### *Path 2: E-Commerce*

Some assistive devices are orphan products -- devices used by very small populations or consumers who are difficult to identify. These orphan devices have limited appeal to companies because they lack assurance that the market exists or that the consumers can be reached. For orphan product, the standard licensing path is inappropriate because the Commercial Package will lack the critical information on market size, or be unable to prove that the consumers can be reached. Even though there may be a persuasive argument for the device's value to consumers, potential licensees will lack sufficient economic incentive to justify the risk of investing resources in the new product. Given the absence of documentation on market size, or even some reasonable uncertainly about market size and interest, how might one demonstrate the product's potential viability? The E-Commerce path offers an opportunity to create a demand for the product, and to even generate preliminary sales. This can be accomplished by identifying an Internet-based company in the business of advertising and selling related products. A dialogue with that company establishes the product's identity, the desired price point, and an agreement to include the product on their World Wide Web site. The next step is to generate a limited production run of the device – fifty or one hundred – and creating the necessary instructions and packaging materials to ship them through the mail. This becomes an e-mail order business, where product is shipped in response to orders placed by customers. It is important to agree on an exit strategy before initiating this partnership, so that the product may still be licensed to an outside manufacturer at a later date.

The Internet is a powerful tool for sellers and buyers to find each other. E-commerce reaches national and international markets. It gives the limited number of intended users the opportunity tin find the product, and it offers the option for others to identify new markets for the same product. As sales accrue, this becomes the baseline data for a revised Commercialization Package. Proving the existence of a market and quantifying that market, helps companies make informed decisions regarding the Standard Licensing path.

The critical success factor for the E-Commerce path – particularly if one is still interested in eventually licensing to an outside manufacturer -- is the product pricing. An item can be produced and offered through e-commerce with fewer mark-ups than a devices offered through traditional distribution channels. So it is tempting to set the price very low. But if the price is set at the minimum necessary to sell through the Internet, it will remain unattractive to an outside manufacturer. They still won't know if it will sell at the price they will need to charge. If the E-Commerce price reflects even a percentage of the more realistic mark-ups of the traditional marketplace, and still sells well, then the Commercialization Package proves the existence of the market for that particular product. One example is our partnership with Dynamic Living. (5)

### *Path 3: Market Cultivation*

Inventors or other product developers may create a product embodying sufficient innovation to surpass the expectations and capabilities of the existing marketplace. Market pricing, government regulations or internal corporate planning determine these capabilities. The Standard Licensing approach will not compel a change, and the innovative product may fall outside the domain of E-Commerce. The manufactures still require an economic incentive, which is difficult to produce when the market for the product does not yet exist. To complicate matters, producing the innovation may require collaboration and investment by more than one manufacturer. Enticing multiple manufactures to pursue an innovation requires the involvement of a market leader. Involving the market leader in the process is the path to market we call Market Cultivation. We define Market Cultivation as nurturing the vision of a new product that exceeds the currently expected product characteristics. This Market Cultivation results in collaboration between the inventor, a potential customer (not necessarily the end user) and one or more manufacturers. The potential customer is typically an industry leader with adequate capital to pay the premium required of market leaders. It is typically a corporation that seeks ways to differentiate itself from the competition, but in the process influence the actions of market followers. The innovative products such a market leader wishes to purchase, often require the capabilities of more than one manufacturer.

This path requires identifying a market leader and imparting the vision for the product, which will differentiate them from their competitors. The vision must include the strategic and tactical benefits of being first to introduce the innovation to the marketplace. When the market leader accepts the vision, the market for the product is instantly established. With the customer on-board, we have the leverage to approach the manufacturers. We are currently engaged in Market Cultivation for a product developed by a partner RERC. (6)

## DISCUSSION:

Successful product commercialization requires creative problem solving skills. External inventions compete for attention and resources against internal projects, including improvements to existing products that are known successes, and new products with internal champions. External opportunities are unknowns, unknowns carry risks, and companies are generally risk averse. To the extent any path to market reduces the real or perceived risk, the chance for success increases. Demonstrating the presence of a market for a product is now as important as demonstrating the need and the technical viability. This is especially true for niche or orphan product markets.

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# CRITICAL SUCCESS FACTORS IN TECHNOLOGY TRANSFER

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## ABSTRACT

This paper describes a research study in progress, which proposes and validates an innovative approach to Technology Transfer, applied to the field of Assistive Technology. It also presents the preliminary findings from the project's first three years.

## BACKGROUND

The Rehabilitation Engineering Research Center on Technology Transfer ($T^2$RERC) seeks to improve the quality of life for persons with disabilities by transferring needed technologies and products into the assistive technology market. We are conducting research to study the feasibility, performance and validity of an innovative approach to technology transfer [1]. The proposed approach differs from the earlier models in its comprehensiveness. It also lends a structured framework to the basic elements focused in earlier research. It initiates the systematic development and consolidation of a model of technology transfer.

## OBJECTIVES:

The purpose of the study is to conduct a *systematic* evaluation [2] of the proposed model through *empirical* observation of its application to transfer of Assistive Technology (AT). Based on a study of the Demand-Pull (DP) and Supply-Push (SP) processes through which the model operates, the study:

- **(a)** Validates the model -benchmark observations from the two processes against the proposed model steps;
- **(b)** Establishes Best Practices -document improvements based on observed critical factors (the *carriers* or the facilitators and the *barriers*), as the two processes are developed.

## METHODS:

The study is designed for an absolute rather than for a comparative evaluation [3]. The observed model performance is judged against the proposed model, not against an external model.

**Evaluation Focus and Questions:**

- **(a)** The *feasibility* of the model - how well does it work?
- **(b)** Its *effectiveness*- extent of success in achieving planned outcomes and
- **(c)** Its *efficiency*-how well does it optimize resources?

The *validity* or relevance of the model to the needs and expectations of the involved stakeholders, to other models and to the technology transfer field in general is an impact issue, and is appropriate for follow-up observations.

**Operational Definitions:** A **Carrier** is a "vehicle" deliberately contrived [during model implementation] in order to facilitate the tech transfer process. Carriers are the *intermediate outcomes* in the transfer process. A **Barrier** is an impediment to transfer; it either obstructs a carrier, or affects its quality, in effect, affecting the transfer. **Best practices** are improvements or alternatives introduced in the model as a result of overcoming the barriers.

## PROCEDURES:

We collect mixed data, combining qualitative and quantitative indicators. We document both sets of data in relation to the carriers, our intermediate *outcomes*. Our *quantitative* observations are person-hours that we systematically track through weekly personnel time sheets, leading to time percentage comparisons between effort expended in developing Carriers. Our *qualitative* observations are the Barrier related information recorded by key SP and DP personnel. Our analyses center around three descriptors of the technology transfer process: 1) How much effort does it take to transfer the technology/ device? 2) How long does it take to do so? 3) What barriers explain the effort and the time to transfer?

Thus, the *time to success/failure* of a technology or a device under transfer, the *effort* put into the transfer process and the *barriers* encountered and overcome are *critical* to understanding the process. Together they tell the entire transfer story. We gain further understanding of the process in relation to the model can be gained by overlaying the data on the model (see Fig 1). The Best Practices that result from overcoming the Barriers complete the documentation and we report results in a case study format [4,5].

## PRELIMINARY RESULTS:

The following is a selected set of examples from SP. A more extensive treatment including transfers through our DP program can be found in the Proceedings of the State of the Science Conference [6].

**Outcomes**: Currently we have achieved the following outcomes through the SP process in the past 36 months: 9 devices licensed to marketing, 14 devices unsuccessful/rejected early in the process and 11 devices still in process.

**Factors Critical to the Transfer Process:**

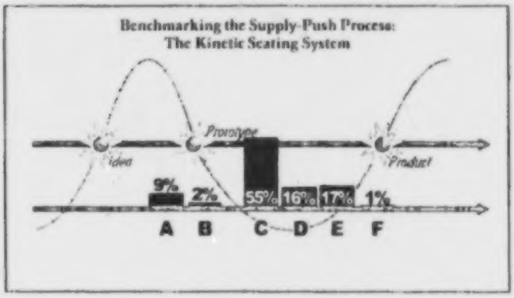

**Fig.1: Effort distribution in transferring KSS**

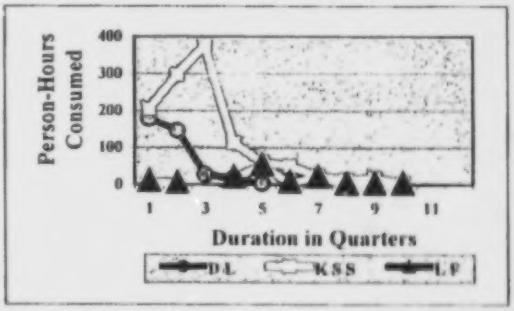

**Fig.2. Effort and time to transfer: three SP devices**

Fig. 1 refers to the Kinetic Seating System (KSS), a successful transfer by the SP process. The sine curve in the background represents the transfer model. The SP *Carriers* are duly positioned along the wave as: **A**. Device Intake; **B**. Agent agreement to license device; **C**. Design needs & priorities; **D**. Commercialization package; **E**. Product licensing agreement; and **F**. Support for product R&D and commercialization. The height of the columns on the graph shows the relative amounts of effort expended for Carriers. Although the Carriers shown in this graph worked for the KSS product, we have other devices that require additional or alternate Carriers. Dynamic Living (DL) is one such case (graph not shown), which used E-Commerce as alternative path to market (See Leahy, 2002 in this volume of RESNA proceedings).

Fig.2 compares KSS and DL with a third device, Little Fingers (LF) to give a more complete picture of what transfer stories can tell. For each device, this graph shows both the amount of effort put into the Carriers (the vertical axis), and the time to success: the length of time it took for the entire process (horizontal axis). LF took relatively less amounts of effort to push through from Carrier to Carrier, but took almost as long as KSS to reach the final transfer stage. The "break" in

LF's graph line between the second and fourth quarters indicates a lack of activity due to "Barriers" that were beyond the control of the process. This pattern of "breaks" in the time line is shared by many of other devices, including those that failed. Stories of specific devices, with their own Barriers and the resulting Best Practices, together go to enhance our understanding of the SP process.

Table 1 illustrates the concept of Barriers and Best practices, in reference to the SP Carrier "Device Intake Package" that is the vehicle related to soliciting, screening and selecting a device for transfer.

**Table 1. Carrier, Barrier and Best Practice: an example**

| Carrier: Device Intake Package [identify promising inventions] | |
|---|---|
| Some Barriers: | Corresponding Best Practice: |
| ➢ High volume and low quality of submissions<br>➢Qualifying the applicant- Difficulties and delays due to organizational protocols & timetables, intellectual property issues, no prototype…<br>➢Obtaining Contact information [confidentiality issues]<br>➢Establishing credibility & getting the inventor interested | ➡ Be selective; work with few, but high quality, submissions<br>➡ Aggressive seeking [USPTO, invention competitions….]<br>➡ Quick Secondary Market research<br>➡ Build contacts early<br>➡ Point out our not-for-profit nature, experience [website], government funding... |

## DISCUSSION – WHERE DO WE GO FROM HERE?

The results from the DP project are analogous to those shown in the previous sections for SP. We are now in the process of cross consolidation of analyses, overall results integration and development of case studies. In parallel, we are attempting an in-depth view of the barriers themselves so lessons in general may be drawn from them for the profession of technology transfer, and, its application to the field of AT.

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# PROJECT IMPACT POST-SECONDARY ACCESSIBILITY DISCOVERIES

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## ABSTRACT

Project IMPACT was established at the University of Wisconsin–Milwaukee with a three-year demonstration grant from the United States (US) Department of Education. Though the demonstration project has been completed, the efforts and recognition of the project have continued and will be expanded to provide the foundation for future accessibility projects. The project started out with a focus on assistive technology service delivery and transitioned to creating accessibility through improved design, while using assistive technology to fill remaining gaps. Project IMPACT recommends that universities begin transitioning from individual accommodation models to using improved design that benefits all student and campus users to meet the needs of individuals with disabilities, in order to more effectively meet the intent of accessibility legislation. This paper summarizes selected Project IMPACT's discoveries.

## BACKGROUND

Project IMPACT is a collaborative effort of academic and administrative units across the University of Wisconsin–Milwaukee campus with common interests in assistive technology and accessibility. Project IMPACT began with fifteen strategies (1) for increasing access to technology. Thirteen different "IMPACT Actions" were described in 2000 based on the projects first 2 years, along with challenges the project encountered in developing an accessible post-secondary environment (2). This paper further synthesizes the project's experiences.

## OBJECTIVE

The objective was to develop, test, and disseminate practices to improve access to technology for students with disabilities in post-secondary environments. It was believed that improved access to technology could assist students with disabilities to remain competitive in a post-secondary environment and thus increase preparedness for employment. This objective was expanded to include access to learning and providing instruction to indirectly affect access to technology. For example, targeting new teaching assistants (TAs) each fall increases the likelihood of TAs having an awareness of accessibility issues prior to encountering students with disabilities in their course or labs, whether in the traditional classrooms, web-based courses, or laboratories.

## METHODS

The discoveries were synthesized by the team members from the project's strategies and experiences. The team members were involved in direct service delivery, consulting, and instruction/training related to campus assistive technology and universal design. The results are based on experiences of the team members rather than specific data. Project IMPACT became involved in a wide variety of activities across campus as part of increasing access to technology. The team found that there were many campus projects, facilities, and personnel groups that affected accessibility of the campus through decision-making or specific design.

## RESULTS AND DISCUSSION

### General Discoveries

Using a team approach across campus units made coordination and timelines a challenge. However, this was also seen as one of the most important aspects of the project. It allowed the team to identify a broad range of issues and projects early enough to become involved in the planning and design stages. This monitoring and sharing of information is critical because it is impractical for a small, isolated group to be aware of all activities and plans across a mid-sized university.

Other discoveries included:

- Assistive technology (AT) and universal design (UD) have an intricate relationship. It is difficult to work on one without consideration of the other.
- It is impractical for people with high-incidence disabilities to be served primarily through one-to-one accommodation services. It is more practical to use improved design that benefits all users in order to improve access.
- AT tends to be an individual accommodation, not accessibility.
- Most campus services that talk about providing accessibility really provide accommodations.
- The A3 Model (3) was helpful for framing a variety of topics and training related to accessibility for audiences with varied backgrounds.
- AT team expertise is needed on campuses to deliver AT services.
- Most anyone, especially with personal computers on the desks of many employees, designs some product, whether it is a building, a brochure, a computer lab, or a lecture.
- Faculty and staff form an important audience for accessibility information. They directly interact with and transfer information to students. They need information that can help them increase accessibility, without having to become experts in the field.
- Universal design strategies and knowledge should be part of the infrastructure of post-secondary institutions. Grant-supported projects cannot provide the long-term campus perspective and follow-through that is needed.

### Campus Universal Design Discoveries

- Campuses are working on pieces, but not addressing the range of issues that could benefit from UD consideration. For example, a campus may look at the physical accessibility aspects of a classroom, but not consider the cognitive or sensory aspects.
- Campuses are unprepared to implement universal design strategies. The primary focus appears to be individual accommodation.
- Change needs to start with faculty and staff. This is an incredibly difficult culture, where academic freedom issues may conflict with accessibility.

### Specific AT Services and UD Discoveries

- Campuses are still providing isolated computer workstations outfitted with assistive technology. In some instances, this is due to cost and compatibility issues related to distributing assistive technology applications to all desktops.
- Some universities buy pre-fabricated multimedia podiums for their classrooms. Others fabricate custom podiums as part of remodeling projects. Often both of these types have

significant barriers for people with cognitive, motor, and/or sensory disabilities. There is a need for podiums to improve cognitive, motor, and sensory accessibility.

Major Accessibility Planning Entry Points

There are many groups or offices on campus that are important entry points for addressing accessibility issues on post-secondary campuses. These include:

- Campus planners – This group plans building and classroom renovation and new construction, as well as transportation systems and outdoor campus environments.
- Faculty and staff, including student services staff – They provide direct instruction in a variety of environments.
- Individual campus departments and units – In a distributed management model, many department and units make decisions about purchasing and design independently.
- Professionals in training – These individuals have the potential to carry next generation accessibility information into their studies and out to future jobs.

Discussion

This information is important to RESNA audiences because of the blend of AT and UD considerations. Project IMPACT notes a need for information related to improving access to technology for students with disabilities and improving the accessibility of post-secondary environments. Project IMPACT will continue developing projects in this area, including taking small findings of the project and developing more detailed explorations.

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# A DESCRIPTION OF NEED FOR INPATIENT ASSISTIVE TECHNOLOGY SERVICES AT A TERTIARY CARE MEDICAL CENTER

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## ABSTRACT

A need and opportunity for assistive technology (AT) services in an inpatient facility is described. The range of inpatients served, their varying needs for AT, and the benefits of providing AT to inpatients are discussed. Data on frequency and duration of service provision are also reported. Finally, a case study illustrating a range of services and specific benefits is presented.

## OBJECTIVE and BACKGROUND

The majority of assistive technology (AT) service provision is done on an outpatient and community service basis. An opportunity exists, however, to provide AT services in acute care settings. This paper attempts to outline the range of services that in our experience (1) can be provided as well as some of the potential benefits of such service provision.

## DISCUSSION

### *A General Description of Inpatient AT Services*

Inpatients have needs for AT in areas including environmental control, seating and mobility, alternative and augmentative communication (AAC), and computer access. Even if such AT is available, hospital staff aware of but untrained in AT may be unable to make appropriate selections. A discussion of how inpatient AT services can fulfill these needs follows.

Environmental control in the inpatient setting includes such needs as control of nurse call, TV, bed, telephone, and other electronic devices in patient rooms. These require accessible interfaces and mounting strategies that can be integrated into hospital systems. Seating and mobility needs can be identified and devices can be provided for home. Changes in mobility needs and maintenance can also be addressed during inpatient stays. AAC systems can be important for inpatients for communication regarding immediate needs and feelings, participation in and organization of care, and for planning for discharge. Computer access for inpatients can prepare them for use of a computer in work, school, and personal use.

Inpatients served vary in disability and in familiarity with AT. Disabilities of inpatients who need AT may be either temporary or permanent, and either stable or progressive. Their need for AT may be new or existing. Patients that fit into each of these categories can benefit specifically from inpatient services for AT. A general description of such services and benefits follows.

For the inpatient whose onset of disability is new but whose condition will be permanent, AT services can be beneficial in many ways. This usually begins with providing assistive access to nurse call and other environmental control early in the acute phase (usually in the ICU). Once these services have been established, other AT can be introduced that facilitates some independence of the patient in a new lifestyle and ultimately allows integration back into the community and possibly to school or work. This can aid the rehabilitation phase by lifting attitudes when patients focus on what they *can* do, and can supplement therapy goals by further incorporating AT in treatment (2). AT services can also be instrumental in discharge planning to help patients make decisions that will allow optimal AT use in the future and build a support network of family and others, including outpatient AT services for continuing assistance with AT use. Following discharge, outpatient AT services can provide more effective service when the patient is already familiar with AT, because the patient can make more effective and informed decisions regarding future technology needs based on experience (3).

Inpatient services may benefit those patients who cannot easily access AT as outpatients or within their community. For example, those who do not have the funding or resources to obtain outpatient AT services after discharge can have access while inpatients even during a short medical stay. This can encourage discussion about community resources and funding resources that could be helpful for their long-term AT needs.

Early intervention of AT services can especially benefit patients with newly diagnosed progressive disabilities such as Amyotrophic Lateral Sclerosis where time is more critical. Having services to address AT with these individuals as inpatients may reduce delays in accommodations as the condition progresses.

Patients who have existing disabilities prior to admission and already use AT at home have a stronger awareness of their own AT needs and typically require this level of independence while in the hospital. In addition, an inpatient stay can provide easy access to technical support for problems with AT at home, or provide easy access to new evaluations and recommendations for AT due to changing goals or needs over time.

Inpatient AT services can also aid patients whose disabilities are temporary, such as those with weakness or loss of communication ability following surgery, or recovery from other medical conditions. Needs of these individuals can easily be overlooked without AT services and as a result many may have needs that go unfulfilled.

*Statistical Representation of AT Services Provided*

The following table includes statistics regarding our inpatient AT service and compares some of these to statistics for the entire medical center. It reflects the magnitude and time for visits of the service we provide.

| Year | AT visits | Hospital admissions | AT visits per admission | Average hours per AT visit | Average pt age: hospital | Average pt age: AT service |
|---|---|---|---|---|---|---|
| 91 | 721 | 36,411 | 0.020 | 0.755 | 34 | 33 |
| 92 | 937 | 37,045 | 0.025 | 0.746 | 36 | 31 |
| 93 | 800 | 36,203 | 0.022 | 0.579 | 37 | 45 |
| 94 | 718 | 37,231 | 0.019 | 0.507 | 37 | 42 |
| 95 | 836 | 35,873 | 0.023 | 0.515 | 39 | 47 |
| 96 | 932 | 34,957 | 0.027 | 0.611 | 39 | 50 |
| 97 | 1122 | 37,591 | 0.030 | 0.531 | 38 | 49 |
| 98 | 909 | 38,884 | 0.023 | 0.561 | 38 | 45 |
| 99 | 1112 | 40,217 | 0.028 | 1.013 | 38 | 44 |
| 91-99 | 8087 | 334,412 | 0.024 | 0.656 | 37.3 | 44.0 |

Inpatient Statistics for 1991 to 1999: University of Michigan Medical Center and AT Service

*A Case Study of a Patient Receiving AT Services from Acute Rehab, and as an Outpatient*

The following case study is in many ways typical for a patient followed by our inpatient AT service. Outcome studies could help to confirm needs of other inpatients in the future; for now, some specific outcomes for this patient are discussed. Following a C2 ASIA A spinal cord injury at age 17, this client was transferred to the University of Michigan Medical Center (UMMC) where acute rehabilitation began. A sip and puff system to access nurse call and control the TV was first established. Next, an integrated environmental control system was set up that allowed him to control the bed, lights, TV, and nurse call in his room via sip and puff. A headset phone was set up to allow private conversations without someone holding the phone for him. He appreciated the independence afforded by environmental control, and felt that it saved time for nursing staff.

Wheeled mobility was addressed with evaluations and training for seating and control methods during rehabilitation so he could sit comfortably and learn to control a power chair while in the hospital. Mobility gave him a feeling of independence. Head control was used for wheelchair control; this ability was improved through use of assistive computer access in therapy.

Computer access training for this client included Morse Code through sip and puff, a head-pointing system for mouse emulation with an on-screen keyboard, and voice recognition. The head-pointing system began to be incorporated into his physical therapy for neck and head movement. Introduction to computer control and other areas of AT showed him that AT coupled with his motivation could realistically allow him to continue his education and pursue a career.

As discharge drew near, our service participated in that area of planning. This client lacked insurance coverage for AT, so we discussed funding sources and other community resources that could help him in the future; these resources later helped him to obtain needed technology and services locally; our service became a liaison to local AT services and other rehabilitation professionals. An intimate friendship was developed with this young man during his inpatient rehabilitation, and this relationship has been maintained ever since.

After several admissions to UMMC and other hospitals over the years for medical problems secondary to his injury, he continues to consider access to nurse call the most critical AT to have in the hospital and feels it is dangerous not to have that access. Also during later admissions to UMMC, our service has been able to address problems regarding his AT at home and provide services to address his changing goals and needs with AT. After discharge, this young man continued to be followed by our outpatient services and use computer control to return to school and is still continuing his education and pursuing other goals in his life. He continues to explore AT on his own and use it to meet his changing needs and goals.

## CONCLUSION

Inpatient AT services can deliver solutions and support for important needs in a tertiary care medical center. Value of these services can be defined in many ways. A description of these services and some ensuing benefits has been presented. One measure of value is cost-benefit. While from a purely financial perspective such services may not be specifically reimbursed (especially in an era of prospective payment and/or cost settlement), they are viewed as a cost effective part of inpatient services. The University of Michigan Medical Center is committed to inpatient AT services as an important component of services needed for a high quality standard of care.

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# PEDIATRIC POWERED MOBILITY: PRELIMINARY RESULTS OF A NATIONAL SURVEY OF PROVIDERS

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## ABSTRACT

A national survey of providers of pediatric powered mobility was conducted to determine demographics of current providers, frequency of powered wheelchair provision to very young children, common reasons for *not* recommending a powered wheelchair, and the reasons why a child who *is* recommended a powered wheelchair does not receive one, current pediatric powered mobility practices and models, typical recommendations for children who are not recommended powered mobility, and finally, baseline data regarding the efficacy of these practices and the impact of powered mobility on the child. A total of 140 surveys were received from providers in 46 states. Preliminary results of several of these items are discussed.

## BACKGROUND

Previous and present 'models' of powered mobility assessment generally involve trial-and-error (i.e., placing a child in a powered wheelchair to determine readiness for driving), and the outcome of the assessment, training and recommendation process is often dependent on the experience and service delivery practices of the clinician and/or assessment center involved. In a 1999 review article, Field stressed the need for a multifaceted approach during the evaluation and recommendation process. While formal research has not been conducted on existing models of practice in the provision of powered wheelchairs to young children, it is presumed that numerous factors may influence the assessment process and the ultimate provision of a powered wheelchair for a young child. Our 5-year RERC project funded by NIDRR is to develop and validate a model for the provision of powered mobility to young children. The first phase of the project has been to conduct a national survey of clinicians and durable medical equipment (DME) dealers to more objectively determine and more formally describe the existing model(s) of practice in the provision of powered wheelchairs to young children. The information obtained from this survey will serve as baseline data to help us compare the efficacy of the new model to present practices and models.

## OBJECTIVES

The objectives of this survey were: 1) to gather background data on individuals providing evaluation and recommendation services and the demographics of their service delivery practices, 2) to determine the frequency with which young children receive evaluations for powered mobility, 3) to identify to most common reasons for *not* recommending a powered wheelchair, and the reasons why a child who *is* recommended a powered wheelchair does not receive one, 4) to gather information regarding the current practices/models used to evaluate a child for powered mobility and typical recommendations for children who are not recommended powered mobility, and 5) to obtain baseline data regarding the efficacy of these practices and the impact of powered mobility on the child. The present paper will describe the preliminary results of the first three objectives.

## APPROACH

The survey was designed following review of literature on wheelchair service delivery and survey development, and after obtaining input from experts in the field of powered mobility. The survey was pilot-tested by ten experts in the field of powered mobility (3 PTs, 1 OT, 3 CRTSs, 1 physician, and 2 researchers) It was refined and mailed to approximately 450 providers whose names were identified via mailing lists of National Seating and Mobility and the RESNA seating and mobility SIG. Follow-up reminders were sent one month later with the goal of obtaining 100 responses.

Respondents were asked to complete the survey based on their experience evaluating two- to six-year-old children for powered mobility during the past *two* years. Information gathered included: demographic information; frequency of service provision; description of the assessment process; number of sessions with the child before a decision was made; number of physician or insurance denials and types of additional information requested; length of time from recommendation of a wheelchair to provision; and recommendations given to family regarding supervision, developmental intervention, transitional mobility devices, and home activities. Respondents were also asked to rank their top three reasons why they do *not* recommend a powered wheelchair and their top three reasons why a child who *is* recommended a powered wheelchair does *not* receive one. Finally, respondents gave a subjective assessment of the child's performance/safety at the time of recommendation and after several months with the wheelchair, and any changes observed in the child's social interactions, play and language skills after several months in the wheelchair.

## RESULTS

*Demographics and background of service delivery practices.* A total of 140 surveys were received from pediatric powered mobility providers in 46 states. This represented a response rate of 56%. Table 1 shows the occupations of the respondents.

Table 1.

| *Current Occupation* | *Percentage* |
|---|---|
| Rehabilitation technology specialists (RTS or CRTS) | 46% |
| Physical therapists | 29% |
| Occupational therapists | 20% |
| Other (rehabilitation engineer, physician, COTA, ATP, etc.) | 7% |

Respondents worked in a variety of geographic locations, including 52% from urban centers, 35% from suburban locales and 13% from rural centers, and in a variety of facility types, including hospital-based (38%), outpatient rehabilitation clinics (18%), school-based facilities (18%), and home-based settings (9%); 18% worked in 'other' facility types.

With regard to equipment, 9% indicated that they did not have regular access to a powered wheelchair during evaluations, and 35% indicated that they did not have access to a 'loaner' wheelchair for children who might require a lengthy practice period. There was no significant difference based on setting (urban, suburban, rural) in routine access to wheelchairs during evaluations (F = 1.23, NS) or to loaner wheelchairs (F = .77, NS). Of those indicating that they did not have access to a 'loaner,' 61% reported that this interfered with their ability to recommend a powered wheelchair.

*Frequency of evaluations.* Respondents were asked to specify the number of children (ages 2 – 6) that they evaluated during the past two years. After reviewing the wide range of responses, we decided to consider this item separately for clinicians versus DME dealers. There was a significant difference between these groups in the average number of children seen ($t = 2.39$, $P<.01$, $df = 84$). The mean for providers was 11.2 (approximately 5 or 6 children per year) with an SD = 15.0 and a range of 0 to 100, while the mean for suppliers was 21.0 (approximately 10 or 11 children per year) with an SD = 28.7 and a range of 0 to 130. On average, providers recommended wheelchairs to approximately 81% of their clients, while suppliers' recommendations were lower at 67%.

*Reasons for recommendations.* The top three reasons (i.e., those which received the most overall votes -- first, second or third) for not recommending a powered wheelchair to a young child were:

1. Child does not mentally understand how to control wheelchair (cognitive factor)
2. Behavioral issues (e.g., poor attention span, lack of judgment)
3. Child not physically able to control wheelchair

The cognitive factor was reported 1.7 times as frequently as the other two reasons, and received 41% of the number '1' votes. The top three reasons why a child who is recommended a powered wheelchair does not receive one were:

1. Request for wheelchair denied by third party payers (i.e., lack of funding)
2. Lack of family support
3. Child's family has no means of transporting wheelchair

## DISCUSSION

The findings indicate that individuals who provide pediatric powered mobility services do, for the most part, have access to powered wheelchairs for evaluation purposes. However, for those children who might need an extended 'practice' period, over one third of respondents reported not having access to 'loaner' wheelchairs. The majority of these individuals stated that this interfered with their ability to recommend a wheelchair for certain children. Interestingly, there was no difference between resources available to providers in urban, suburban or rural areas. The three most common reasons for not recommending a powered wheelchair to a young child related to cognitive difficulties with the wheelchair, behavioral issues and a physical inability to control the wheelchair. These will be important factors to include in the new service delivery model to be evaluated by this project. In addition, the top three reasons why a child who is recommended a powered wheelchair does not receive one (lack of funding, lack of family support, and transportation) will also be important factors. The project is beginning a prospective study at three centers that will evaluate a new model based on survey results and on previous work in our center.

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## ACKNOWLEDGEMENT

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# Design of a Clinical Observation Experience Program for Undergraduate Students in Engineering

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## ABSTRACT

Our student group, Rehabilitation Engineering Medicine, (REM) works with the Rehabilitation Medicine Department of the University of Wisconsin Hospitals. As part of an experiential design course, we work with rehab medicine to design engineering-based systems for providing better patient care. Current and past projects include designing vital sign equipment carts, and improving the patient escort system. What is reported on here, however, is not the design of a specific physical artifact. Instead, it is a description of a design undertaken by our team to develop an innovative new program, the Clinical Observation Experience (COE), aimed at providing the necessary clinical experience for undergraduate engineering students interested in rehabilitation medicine. We hope that this program design will serve as a model for other institutions interested in developing comparable opportunity for their students with similar interests.

## BACKGROUND

Engineering Projects in Community Service (EPICS) was started at Purdue University in 1995. EPICS was created to establish partnerships between teams of undergraduate students and local community organizations to work together on engineering-based problems in the community (*fg.* Please see the Purdue and UW EPICS websites). This partnership provides benefits to the students and the community alike. It places the students in direct contact with community clients and, in doing so, gives the students a taste of real problem solving in a team-based environment. Equally, the community organizations receive insights and solutions to their problems from students who work on these issues within their own curriculums. Often times, the students have provided services and solutions that were significantly less expensive than similar offers from professional providers. An example of this was the vital sign equipment carts project. A retail product that most closely met the client's needs cost over $500 each. Our team, REM, designed, constructed, and delivered a custom product for less than $200 apiece.

REM is an element of the University of Wisconsin's EPICS program. REM currently serves the UW-Hospital and Clinics Department of Rehabilitation Medicine. In a partnership with UW-Hospital, REM strives to help identify potential and current problems at UW-Madison Hospital by engaging students in observation, research, and participation with patients and staff. By engaging in direct interaction with the department, REM can not only serve to improve patient care and medical practice within the hospital, but also allow students to have a more practical, and less theoretical education experience.

## STATEMENT OF THE PROBLEM

In previous REM experiences at the hospital, students were not allowed to observe certain processes, nor inquire as to how these processes were performed and why. For instance, anything relating to the type and physical delivery of specific medicines was off limits, as was the nature of the patients' therapies. Understandably, personal information of this type should be restricted ,however, as students working to improve patient care, REM was hindered because of lack of access to such a large part of what occurs in patient care. As a result, information gathering has been limited to methods such as surveys, non-specific questions, and limited patient care observation. This meant that many questions about the patient care problems and how to address them went unanswered. As a result, the solutions offered by the REM were only capable of addressing the more superficial aspects of the problems, without getting to the larger, foundation issues and truly solving them.

## OBJECTIVE

The aim of our design in establishing this program was to form a clinical experience partnership, termed the Clinical Observation Experience or COE, between the UW Hospital and EPICS REM undergraduate engineering students. The goal here was to fully expose EPICS students to clinical engineering and patient care environments while offering valuable problem analyses and solutions to the hospital. By assessing the department's processes from an engineering perspective, we offer the hospital services that they may not otherwise receive. In order to do this, REM students need direct observation experience and clearance to inquire about additional information regarding patients and processes.

## DESIGN AND MATERIALS

An introductory program policy draft was created by REM, which stated the purpose and goals of the program. It was designed to outline both the importance and background of REM and its relationship with the Rehabilitation Department. The Nursing Administration of UW Hospital already had a policy regarding clinical observation for nursing and medical students, and this was used as the basis for REM's draft. This draft incorporated the clearance regulations and documentation of the original, and added the purpose, methodology, contact information, and future plans of the program and REM. Please see Table 1 below for the policy's main operating rules.

| Scheduling/Accompaniment | Access to Information | Group size | Materials |
|---|---|---|---|
| • Students would give notice of expected observation times, in either direct, email, or phone message form.<br>• Escorted only if required for patient or permissions | • Only information pertinent to the research would be requested from the staff/patient<br>• Permissions may come down to the individual patient's wishes | • Students can observe individually.<br>• Group size subject to traffic level in department | • Lab coat<br>• ID Badges<br>• Secondary Identification (Student ID, Driver's License, etc.) |

Table 1: Observation experience details

Also stated in REM's plan were guidelines concerning patient confidentiality and health regulations. The hospital requires various health and signed confidentiality forms of patient-care workers, volunteers, and interns. These requirements would also apply to the REM members when partaking in any element of the COE. Among other things, these forms ensure that each participant is screened for dangerous and/or contractible diseases, and frees the hospital from liability in the case of an accident. A packet containing the policy agreement, any information pertaining to participation in the clinical experience, and health form requirements will be required of all future participating members of REM, to be delivered before the first clinical observation. The contents of this packet are as follows:

- A tuberculosis (TB) skin test with a zero or negative result
- A criminal background check

- A signed copy of the UW Hospital's patient confidentiality agreement
- Any further documentation to be required by the hospital in the future

In addition, the hospital requires all staff personnel and employees to have physical identification. A result of this mandate is that an air of professionalism and clarity of who belongs is present. This convention will be maintained by REM through the purchase and use of standard lab coats and ID badges. The professional attire worn by REM students will aid in establishing an official presence in the hospital, which will assist in opening up discussion with patients or staff.

## DISCUSSION

A proposal for the program has been drafted and students have acquired proper health clearances to go forward with the testing the effectiveness of the program. This testing entails REM members executing the clinical observation of patients and staff for the purpose of finding problems or potential improvements to the hospital's current processes. Students and selected hospital staff will be asked to comment on any problems they have encountered and to suggest any modifications to the existing format. If necessary, students will then re-design the program at the end of the semester in preparation for the following one. Please see Figure 1 below for an illustration of this process:

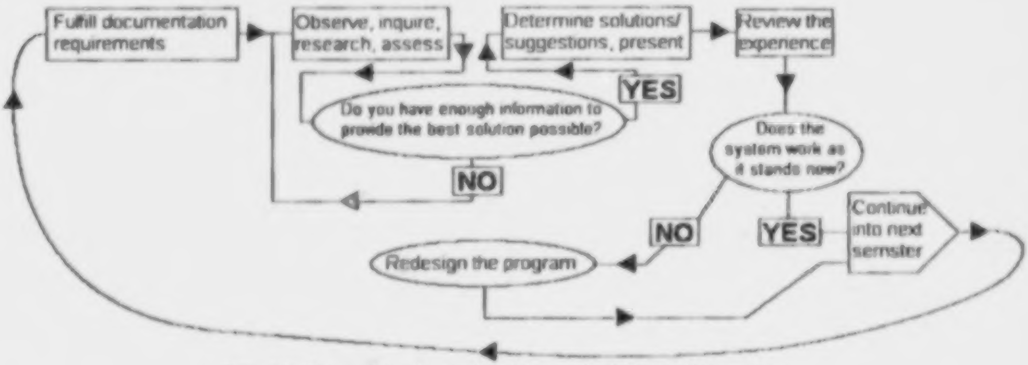
Fulfill documentation requirements
Observe, inquire, research, assess
Determine solutions/ suggestions, present
Review the experience
YES
Do you have enough information to provide the best solution possible?
NO
Does the system work as it stands now?
NO
YES
Continue into next semster
Redesign the program

Figure 1: The participation and revision cycle during each semester.

Every subsequent semester, a kit will be assembled that will contain clinical observation experience information and guidelines, proper health forms, the patient confidentiality agreement, and information on TB testing. Therefore, EPICS students wishing to participate in the program will have all the necessary forms and information readily available.

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## ACKNOWLEDGEMENTS

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# Quantifying Function and Outcomes (Topic 7)

# MAINTAINING BALANCE IN SEATED REACHES

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## ABSTRACT

The aim of this study is to gain insight into how people maintain their balance while performing seated reaches. The requirement to maintain balance is a significant contributor to reach difficulty, and in some cases exceeds strength and range of motion as the primary limiting factor in achieving a specific reach. Maintaining balance is often more difficult for people who use wheelchairs (Figure 1), particularly for those with a spinal cord injury. A better understanding of balance-maintaining behavior will allow development and improvement of tools for the design of workspaces and other environments. This paper details a method for investigating the role of balance in seated reaches and presents preliminary results.

## BACKGROUND

The tactics by which people maintain their balance when seated have not been extensively studied. Dean et al. (1,2) presented the results from two research projects involving seated reach and the role of the lower limbs in maintaining balance. Using electromyography (EMG), they showed that the lower limbs become increasingly active as the distance of the reach increases.

In a study of people with spinal cord injuries or low back pain, Womack, et al. (3) measured the EMG activity in arm, shoulder, and back muscles during forward and lateral reaches. The motion trajectories and subjective difficulty of these reaches were also recorded. Seelen, et al. (4) found that people with a thoracic spinal cord injury had a reduced capacity for moving their center of pressure. A reduced ability to move the center of pressure is related to reach difficulty and limitations in maximum reach envelope, as shown in static conditions by Chaffin, et al. (5).

## RESEARCH QUESTIONS

The objective of this study is to increase understanding of the role balance-maintenance plays in the difficulty and dynamics of seated reaches. It expands on the work of others by investigating dynamic, rather than static, conditions and by measuring both the location of the center of pressure and the forces exerted by the non-reaching hand. Additionally, the contributions of the contralateral hand have not been studied extensively, particularly when used to compensate for inactivity in the lower limbs.

## METHOD

The experimental setup is shown in Figure 2. Twelve men and women without a mobility impairment selected by age and stature performed a series of reaches and rated their difficulty. In each of these reaches, the participant started in a "home" posture, reached toward a target button

Figure 1 – A person with SCI performing a loaded reach.

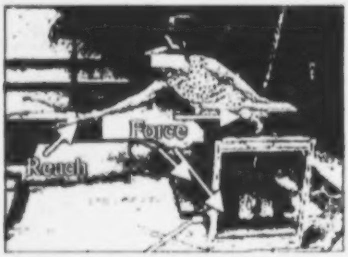

Figure 2 – Experimental setup for current study.

and depressed it for two seconds, before returning to the home position. The forces and moments under the trunk and feet were recorded, as well as those exerted by the non-reaching hand. A pressure pad measured the pattern of pressure at the buttocks/seat interface. Additionally, the angles and trajectories of various anthropometric landmarks were recorded throughout the reach. After completion, the participant rated the difficulty of the reach on a scale from 1-10 and ranked three factors (balance, range of motion, and obstruction) as to their contribution to the difficulty of the reach. Each participant performed a series of reaches in each of six radial planes (-30°, 0°, 30°, 60°, 90°, and 120° with respect to straight ahead, positive to the right). The design of the study was such that every participant performed near-maximal reaches in a wide range of directions, so that a range of balance-maintaining tactics may be observed. The subjective data obtained during the study provides a means of relating the balance requirements of the task to the perceived difficulty.

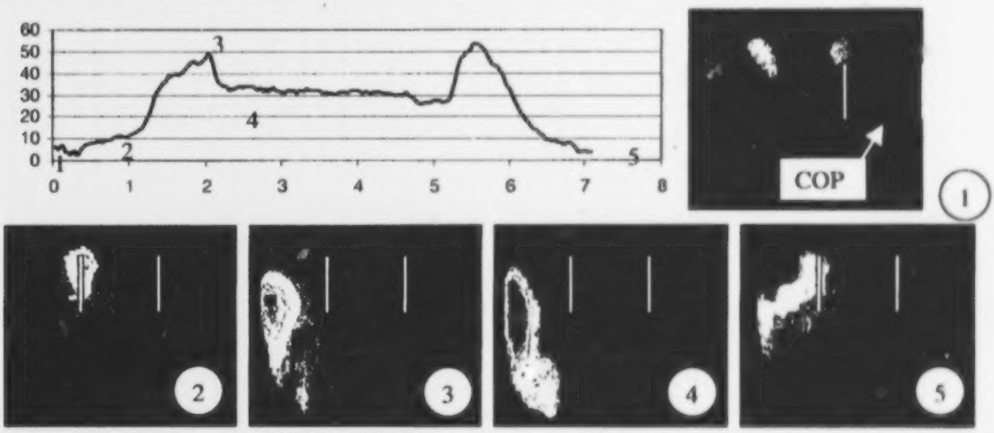

FIGURE 3 - Force and pressure results from an unloaded, lateral reach.

## RESULTS

Figure 3 shows the results of a subject performing an unloaded lateral reach. The graph presents the forces in the contralateral hand as a function of time. The five frames show the location of the dynamic center of pressure (COP), the initial approximate location of the ischial tuberosities (vertical lines), and the pressure distribution across the buttocks/seat cushion interface. At rest (Frame 1), the COP is centered between the tuberosities and the hand force is near zero. In Frame 2, the hand forces have begun to increase—even though the COP is well within the tuberosities (hence the body would likely be in static balance without the contralateral hand force). In frame 3, the COP has moved outside the location of the tuberosities and the hand force reaches a maximum. The force decreases to an equilibrium value while the subject presses and holds the button (Frame 4) and the COP moves even further out. After releasing the button, the subject returns to the home position. Another spike in the contralateral hand support force is observed as the subject moves the upper body back to the "home" position. The hand force returns to 0 as the COP moves inward.

## DISCUSSION

The magnitude of the peak hand forces (Frame 3 of Figure 3) exceeds that of the of the force plateau resulting from the time the participant presses the button. This is an indication that balance-maintenance is a dynamic phenomenon. If static predictions were adequate, there would be no peaks in force.

As the center of pressure nears the location of the right ischial tuberosity, the subject relies increasingly on the support of the contra-lateral hand to maintain balance. Since the center of pressure moves beyond this point, this reach could not be performed without something for the subject to hold on to (in this case, a table) or extreme repositioning of the lower extremities. Note that the hand exertion forces increase before the center of pressure instability position (over the ischial tuberosity) is reached. The sitter apparently anticipates that additional support will be required to complete the reach and implements exertion of the non-reaching hand early.

These preliminary results indicate that balance maintenance is an important facet of reach behavior. As this research is extended, the results should aid in the creation of a model of dynamic balance-maintenance during seated reaches.

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# USING THE WWW TO STUDY THE EXPERIENCES OF PERSONS WHO USE WHEELCHAIRS: LOCAL AREA VERSUS DISTANT PARTICIPANTS

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## ABSTRACT:

A larger study with four hypotheses was designed to quantify the effect of exposure to WheelchairNet on consumers' self-rating of readiness to participate in wheelchair decision-making. One hypothesis tested the concept that there is no difference between participants designated as a local group and those as a national group. A result of "no difference" was expected demonstrating that Internet-based studies offer a method that allows researchers to extend beyond local participants who are usually studied using face-to-face strategies. A significant finding ($p=.002$) led to rejection of the $H_0$ but for a different reason. A post hoc analysis showed a difference between participants in the SW US (primarily Californians) and SW Pennsylvanians on Powerful Others Health Locus of Control. Findings support use of national samples of wheelchair users to overcome unrecognized local bias when studying consumer attitudes, beliefs, preferences and experiences.

## BACKGROUND

WheelchairNet (http://www.wheelchairnet.org/) was designed as a means to inform the broad community of persons interested in wheelchair mobility technology and interact with them through discussion and technical assistance. It was assumed that the website offered visitors an opportunity to learn, but it was not known if the effect of this exposure could create measurable results. Quantifying the effect of this website justifies the investment of time and resources in website development. Many consumers live in small communities and rural areas and have limited choices in practitioners and/or suppliers. This scarcity of experienced professionals is especially challenging when consumers are preparing for new wheelchairs and want to explore equipment options and understand their potential impact on daily living, function and independence.

A study of the impact of WheelchairNet on consumer decision-making was undertaken as a task of the RERC on Wheeled Mobility and the author's doctoral dissertation. The study had several purposes one of which was to determine if comparison could be made via Internet between consumers living in the local area and those dispersed across the country. Researchers working with local participants already know attributes like topography, climate and social attitudes. They also know, in general, about the density of rehabilitation services and rehabilitation technology supplier resources. These attributes vary widely by community and across the country. When participants are only known by Internet and telephone interaction these attributes cannot be judged in the same way. In attempting to compare individuals in these two groups, the interest was to demonstrate evidence groups that there is no difference between groups. This similarity would add support to using Internet-based surveys to learn about attitudes, beliefs, preferences and experiences among persons with disabilities who are geographically dispersed. This could expand the pool of applicants who met study admission criteria and were available to participate in research studies.

A Literature review supported the idea that adult decision-making is influenced by an individual's locus of control [1], their personal goals, knowledge of options, and desire for options that support goal achievement [2]. This literature was used develop several instruments used in a larger study with four hypotheses. The test-retest reliability and validity of these investigator-developed instruments was determined to be adequate for use [3]. Two study hypotheses focused on quantifying the effect of exposure to WheelchairNet on consumers' self-rating of readiness to participate in wheelchair decision-making. One comparison was between experimental and control groups and another between local and national groups. Effect was measured by comparing pre/posttest scores on measures of Multidimensional Health Locus of Control (MHLC)[4], life goals[5], self-assessed knowledge of wheeled mobility, desire for wheeled mobility device characteristics. The two remaining hypotheses in the larger study examined consumers' ratings of the ease of gathering information via the WWW and the relationship between time and resources used on the site and pre/post change scores. The purpose of this paper is to share the findings on one study hypothesis that has implications for AT researchers. This hypothesis was designed to compare performance of local area participants with that of participants from across the United States.

## HYPOTHESIS

The relevant study hypothesis stated: "There will be no difference between participants who use wheelchairs and have access to the Internet living in the local area and those geographically dispersed across the United States as measured by study pre and posttest scores. Scores on measures of health locus of control, life goals, self-assessed knowledge, desire for device characteristics, and readiness to participate will be compared."

## PARTICIPANTS

Seventy-one out of 108 volunteers met admission criteria and completed the study. All participants supplied a physician-signed affidavit as evidence of wheelchair use. Gender and age were equally distributed however participants had more education, higher income and higher likelihood of quadriplegia than expected. The means years of WC use was 18.7 (sd=11.9 yrs.) making participants experienced wheelchair users. Participants came from 25 states and were assigned to 6 regions. Within the NE region, 11 lived in ZIP codes predetermined to comprise southwestern PA and thus formed the "local group."

| Northeast | | Southeast | | No. Central | | So. Central | | Northwest | | Southwest | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CT | 1 | FL | 1 | IN | 1 | KY | 1 | OR | 1 | AZ | 2 |
| DC | 1 | NC | 1 | MI | 1 | KS | 3 | MT | 1 | CO | 2p |
| MA | 1 | VA | 7 | MN | 1 | MO | 9 | WA | 2 | CA | 10 |
| DE | 1 | | | WI | 2 | | | | | UT | 2 |
| MD | 2 | | | OH | 3 | | | | | | |
| PA | 14 | | | ND | 1 | | | | | | |
| Totals | 20 | | 9 | | 9 | | 13 | | 4 | | 16 |

All participants completed study instruments by logging in to web page forms related to a database that collected and stored item responses. Participants in local and national groups were randomly assigned to either experimental or control conditions. The experimental group used a password-protected clone of WheelchairNet (to track site usage) for 6 weeks. The control group used the WWW normally but was asked to refrain from searching the WWW on wheelchair-related topics. All participants were asked to account for non-WWW sources of wheelchair-related information.

## RESULTS

Although it was hoped to have equal-size groups, only 11 participants were recruited into the SW PA group. No comparison between groups on measures of life goals was possible and data was analyzed qualitatively. A statistical comparison on measures of health locus of control and desire for device characteristics using ANCOVA with pretest as covariate showed no significant difference(p=.2) between local and national groups. To increase confidence in the presence of group size disparity that the groups were actually from the same population, a second test was performed. A one-way ANOVA comparing the location groups on each of the pretest dependent variables was used. This comparison assumes that if the groups are not significantly different on the pretest, then they are likely from the same population. It could be expected that their scores on the posttest would be related to their randomization to the experimental condition rather than geographic location. Again there was no difference between groups except on one measure—a subset of the MHLC called *Powerful Others Health LOC.* A significant statistic (p=.002) supports the premise that the SW Pennsylvania group has a significantly higher belief that one's health is influenced or controlled by others. Post hoc analysis with the Tukey HSD showed the significant difference in means was specifically between the SW PA group and the SW US group dominated by 10 members from CA (Group composition = AZ=2, CA=10, CO=2 & UT=2).

## DISCUSSION

The post hoc analysis, in segmenting the comparisons by geographical region helped explain the meaning of the finding. When reduced to this comparison, it is plausible that SW Pennsylvanians are different from Californians. Berkeley, CA is the birthplace of the Independent Living Movement, and is considered a model for accessibility and community inclusion [6].

This unexpected finding suggests that including participants from broad geographical distributions contributes greatly to normalizing the distribution of characteristics in a study sample especially when studying attitudes, beliefs, preferences and experiences. It is common practice for researchers to reach out to convenient local participants using strategies of random selection and assignment to control variance. This study finding supports the idea that unrecognized biases may exist in regional samples. Inadvertent and unrecognized skewing of study findings can be avoided with broad national sampling as is possible via national recruitment and Internet-based studies.

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# INFLUENCE OF WHEELCHAIR SERVICE DOGS ON HUMAN ASSISTANCE NEEDS IN BASIC AND INSTRUMENTAL ACTIVITIES OF DAILY LIVING

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## ABSTRACT

Research has found individuals partnered with wheelchair service dogs (SDs) to be less reliant on human assistance compared to similar individuals without service dogs, though the results have varied (1),(2). Therefore, a longitudinal study examining the influence of wheelchair SDs on use of human assistance was conducted. Two trends were found in the data, though differences were not significant. First, hours of human assistance utilized for instrumental activities of daily living (IADL) remained stable in the SD group (n=14), while an upward trend was noted for the control (waiting-list) group (n=19). Second, the SD group's need for assistance in transportation to healthcare appointments declined at nine months, while the control group's need increased, though the number of monthly healthcare appointments was more than twice that of controls.

## BACKGROUND

A randomized clinical trial was conducted in 1996, which examined the impact of SDs on psychological and economic characteristics of individuals with disabilities (1). The treatment group included 24 individuals who received SDs one month after enrollment, and the control group consisted of 24 individuals who received SDs 13 months after joining the study. Data was collected every 6-months during this two-year study. The authors reported a 68% decrease in paid assistance hours after one year of SD ownership, suggesting a savings of approximately $55,912 per owner over the eight-year working life of a SD. A similar reduction of 64% in unpaid human assistance hours was also reported. This study is controversial and has been challenged by researchers due to magnitude of effect size and absence of methodological detail (3), (4).

Less dramatic reductions in human assistance costs for 202 individuals with SDs were found in a cross-sectional study by Fairman and Heubner (2). Hours of paid human assistance declined by approximately two hours per week after receiving a SD, an average savings of $600/year. Similarly, unpaid human assistance dropped by approximately six hours per week.

Hours of human assistance were not directly measured in a longitudinal study with 1054 elderly participants and their pets conducted by Raina et al. (5). However, the study demonstrated that pet ownership maintained or slightly enhanced levels of independence in ADL. However, pet owners, on average, were younger than non-pet owners, which may have confounded the study results.

Health status, income and pet ownership were found to be major determinants of frequency of physician contacts in a study of 938 Medicare recipients by Siegel (6). Pet owners made fewer MD visits. Therefore, Siegel suggested pet ownership benefited individuals, not by improving general health, but by providing social and psychological benefits.

## RESEARCH QUESTION

How do wheelchair SDs influence the utilization of human assistance in completion of basic and instrumental ADL, as well as number of monthly healthcare visits?

## METHOD

Study: A nine-month, case/control, longitudinal study comparing psychosocial and functional characteristics of individuals partnered with and without SDs was conducted. Cases included 14 individuals partnered with SDs, and controls were 19 individuals on a waiting list to receive a SD with a service dog organization. Baseline data were collected when participants entered the study, and were obtained prior to receipt of SD for those in the SD group.

Questionnaires were used to collect data, and included questions regarding sociodemographics, healthcare utilization, ADL and IADL, and psychological characteristics. Data on hours of human assistance utilized were obtained at baseline, 3 months, and 9 months from enrollment.

Analytical Methods: All data were analyzed with descriptive statistics, and outliers were transformed. Continuous data were analyzed with repeated-measures ANOVA when appropriate. Data not normally distributed were dichotomized when appropriate. Categorical and dichotomous data were examined with chi-square tests. Alpha was (p=0.05) for all statistical analyses.

## RESULTS

No significant differences were found between the SD group and controls at baseline. Initial demographic information described the average SD owner as a single, 39.2-year-old Caucasian female with a spinal cord injury who received employer-sponsored health insurance. The typical control was a married, 44.9-year-old Caucasian female who also had a spinal cord injury and relied on Medicare for healthcare expenses. The average SD and control participant had education and degrees beyond high school, personal income below $20,000 per year, and household income exceeding $20,000 per year (Table 1). During the nine-month study, SD participants were more likely to experience decreases in personal or household income.

| | | SD Group | Controls |
|---|---|---|---|
| **N =** | | 14 | 19 |
| **Gender** | Women: | 8 | 13 |
| **Age** | Mean :<br>(SD): | 39.2<br>(10.6) | 44.9<br>(9.7) |
| **Race** | Cauc.: | 12 | 16 |
| **U.S. Veteran** | | 1 | 1 |
| **Prim. Diagnosis** | SCI: | 6 | 10 |
| | CP: | 2 | 0 |
| | MS: | 2 | 4 |
| | Other: | 4 | 5 |
| **2nd Diagnosis** | CVD: | 2 | 1 |
| | Diabetes | 3 | 3 |
| | High BP | 4 | 5 |
| | Arthritis | 1 | 5 |
| **Married** | | 4 | 12 |
| **Educ./Degree** | > High Sch: | 12 | 15 |
| **Pers. Income** | <$20,000 | 8 | 10 |
| **Household Income** | >$20,000 | 9 | 15 |
| **Insur. Prov.** | | Employer | Medicare |
| **Avg. MD appt.** | | 6.2 | 2.3 |

**Table 1: Demographics, by Groups**

Repeated-measures ANOVA was used to analyze differences between SD and control groups, as well as differences within each group over the 9-month study. No significant differences were found when examining the hours of human assistance utilized for ADL and IADL, monthly hours for healthcare/MD appointments, or transportation to healthcare appointments. In addition, neither group demonstrated significant changes in hours of human assistance required in these categories over time.

## DISCUSSION

At baseline, individuals partnered with SDs were more likely to be single, less likely to have arthritis, and covered by employer-sponsored insurance. Controls were more likely to be married, had a higher chance of having arthritis, and were on Medicare.

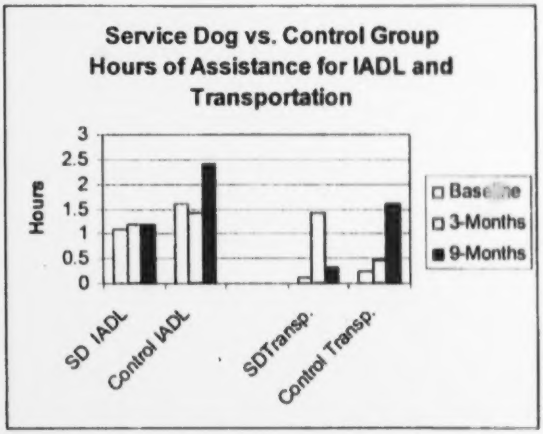

**Fig. 1: Assistance Hours for IADL & Transportation to Medical Appointments**

Though no statistically significant differences were found between the groups in need for human assistance in basic and instrumental ADL, monthly healthcare visits, or transportation to healthcare appointments, two trends emerged (Fig. 1). Hours of human assistance required for IADL by the SD group remained stable over time, compared to controls, which increased at 9 months. Likewise, hours for transportation to healthcare appointments peaked for the SD group at 3 months, but fell at 9 months though the average number of monthly appointments for the SD group was 2.6 times that of the controls at 3 months and at 9 months. In addition, the control group's hours of healthcare utilization grew steadily.

This study does not support the findings of previously published research on service animals and human-animal bonding, possibly due to small sample size, or short follow-up time period (9 months) of all participants. Being an intent-to-treat study, seven participants were in the process of completing the study while nine were lost to follow-up from the baseline number of 33 participants. Limitations of the study include self-reported data, inability to randomly assign SDs to case versus control groups, and recruitment of participants from two service dog agencies.

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# DEVELOPMENT AND RELIABILITY TESTING OF A CLINICAL RATIONALE MEASURE OF SEATING AND WHEELED MOBILITY PRESCRIPTION

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## ABSTRACT

The purpose of this project was to develop a measure to quantify clinical rationale of wheelchair and seating prescription. This paper will present the development process of the clinical rationale measure and report reliability test results.

## BACKGROUND

A review of the literature reveals a dearth of research related to effective means of increasing the level of competence and proficiency of professionals working in the field of seating and wheeled mobility. Prescribing wheelchairs and seating systems is typically completed by a team consisting of the client, rehabilitation technology supplier, therapist and physician.

The therapist usually performs the physical, functional and environmental evaluation. The scope and depth of evaluation skills of the therapist can vary widely. Varying levels of competence result in comparably varying quality of advice and equipment prescription for consumers [1]. Unfortunately, experienced and/or specially educated physical therapists (PT's) and occupational therapists (OT's) trained to provide seating and wheeled mobility prescription can be hard to find [1, 2]. Many feel that targeted professional training will maximize the consumer/technology match [2]. In order to pursue research that investigates the most effective way to improve competency and proficiency of professionals, a tool measuring clinical competency and proficiency is required. Currently, there is no existing tool.

## PURPOSE

The purpose of this paper is to describe the development process and scoring method used to evaluate clinical rationale of seating and wheeled mobility prescription skills. The rationale clinicians use to prescribe wheelchairs and seating systems was studied by examining the documented thought process used for a case example. Reliability testing of this measure was completed.

## DEVELOPMENT & EVALUATION

The development of the Clinical Rationale Assessment of Prescription, a quantitative testing and scoring method was completed over two separate trials. The first trial included a group of 20 PT and OT students about to enter the field; the second trial involved 89 PT and OT professionals with varying levels of experience in seating and wheeled mobility prescription. A videotape of an assistive technology practitioner performing a seating and wheeled mobility evaluation of a client was made in order to standardize information presented to subjects. Subjects were provided with a generic wheelchair prescription form consisting of three columns (problems, goals and recommendations). They were then asked to identify and document client problems, translate them into goals and write a complete generic prescription recommendation for a wheelchair and seating system. Test duration was approximately 1½ hours (45 minute video, 45 minute documentation).

A panel of 6 "expert" clinicians, with an average of more than 12 years of seating and mobility prescription experience, were selected and polled to create a list of common seating and mobility problems, goals and equipment features. This list was used to generate a checklist-grading sheet to transfer data from subjects' test sheets.

Two unique "expert" clinicians viewed the videotape separately and completed the checklist-grading sheet. They then reviewed the checklist-grading sheet, and together discussed what constituted a "correct" response. The agreed-upon response became the "gold standard" key. The two independent scorers then completed a practice scoring session using two tests from the first trial. The two scorers graded these two tests then compared, discussed and reached consensus about the use of the checklist-grading sheet. The subjects' checklist-grading sheet was then compared to the "gold standard" answer key of potential "correct" answers. A score for each subject was tallied based on four areas: correct problems (CP), correct goals (CG), correct recommendations (CR), and correct grand total (CGT) responses. The scorers then graded a set of 20 tests from the first trial of the study. These results were tested for intrarater and interrater reliability (Table 1).

Upon completion of the first trial, "expert" scorers met to discuss modifications of the scoring sheet. This entire process was repeated for the development of version 2, the revised checklist-grading sheet and "gold standard" answer key. Items on the grading sheet were reorganized, clarified or omitted when redundant. Then a second practice scoring session was completed using 5 tests from the second trial. Following the practice scoring session, the grading sheets were compared, discussed and consensus reached. A new "gold standard" answer key was completed using the revised checklist-grading sheet. The scorers then graded a separate set of 20 tests from the second trial. These results were tested for interrater reliability (Table 1)

## RESULTS

In trial one intrarater reliability was poor except for one category (CG) with ($r > 0.75$). Interrater reliability was also poor except for one category (CR) with ($r > 0.75$) (Table 1). Due to low reliability, the checklist-grading sheet was revised and retested in trial two. Again, interclass correlations resulted in poor to moderate reliability with only one category (CP) with ($r > 0.75$).

**Summary of Reliability Testing**

| | ICC range for all categories* (r value) | Categories with $r > 0.75$, $p < 0.05$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Potential score range | Range of scores | SD | SEM | 2SEM |
| Intrarater Reliability (n=3) | -.22 to .77 | CG | 0-21<br>Gold Standard V1 | 8-14 | 2.48 | 1.20 | 2.40 |
| Interrater Reliability Trial 1 (n=20) | .23 to .82 | CR | 0-20<br>Gold Standard V1 | 5-15 | 2.28 | 0.97 | 1.95 |
| Interrater Reliability Trial 2 (n=20) | .42 to .89 | CP | 0-49<br>Gold Standard V2 | 18-39 | 6.10 | 2.21 | 4.43 |

(Table 1) CG=correct goals, CR=correct recommendations, CP=correct problems, CGT= correct grand total
all categories*= CG, CR, CP, CGT

## DISCUSSION

It is difficult to develop a measurement tool that will provide evidence of competency and rationale since, they are abilities that are not tangible; they, therefore, must be inferred. Because ability is dependent on contextual or situational factors, it is difficult to develop a reliable and valid measurement tool that will include the factual knowledge, clinical skills and professional judgments a clinician must demonstrate to provide evidence of competency [3, 4]. In test situations, researchers are challenged to standardize patient examples and protocols in order to increase reliability of clinical grading. This practice often compromises external validity. Typically,

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competency tests are performed because we intend to draw conclusions about a clinician's ability in nonstandardized contexts [3].

The intrarater and interrater reliability results of this clinical rationale measure primarily show values below .75, which according to Portney and Watkins, are indicative of poor to moderate reliability. "However, these limits must be based on the precision of the measured variable"[5]. Portney and Watkins suggest guidelines for clinical measurements should "exceed .90 to ensure reasonable validity"[5]. Standard error of measurement (SEM) is one statistical method used to express response stability or measurement error. There is a 68% chance that individual true scores fall within 1 SEM and a 95% chance they fall within 2 SEM. In order for two test scores to be truly different they must be at least 2 SEM apart. The standard deviations (SD) in Table 1 are greater than 2 SEM indicating that although these categories are statistically significant there is 95% chance that this significance is due to chance. According to these findings, this measurement tool is not precise or sensitive enough to detect true measurement differences, a significant limitation in this tool. Other limitations of this measurement system include: decreased use of the total possible measurement scale as reflected in the limited observable range of scores and decreased generalizability of this tool to other nonstandardized contexts due to the specificity of the one case example. The limitations of this test instrument are a threat to study validity and cause us to question findings in our previous research [6, 7]. Future work will include the development and testing of a clinical rationale measure based on what we have learned and applying different strategies towards its development.

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# The Development of Digital Human Models of people with disabilities for use by designers and clinicians

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**Abstract**

The main problems targeted by this work are the *Lack of Designer orientated Human Modeling Software*, and the subsequent, *Lack of ergonomically correct products and environments* which are useful to persons with disabilities. This work aims to develop a Functional Visualization System for the development of Digital Human Models (DHM) of people with disabilities for use by designers and clinicians. The system will include standard measurement procedures for the capture of anthropometric data, the development of computer programs and processes for the visualization of the data which has been captured, a verification method and rig to verify the accuracy of the data captured, and documentation of the system's use by designers and clinicians for the creation of specific products and environments, which are created to solve particular problems encountered by people with disabilities.

**Background**

Over the past four decades the prevailing wisdom about the cause of disability has undergone profound change. Previous models of disability which viewed disability as a pathological process are being replaced by models in which disability is seen as an interaction between the characteristics of the individual with disabling conditions and the characteristics of their environment. The level of disability is not determined merely by levels of pathologies, impairments or functional limitations. Instead it is a function of the extent to which the social and physical environment is accommodating to their particular needs.

**Statement of the Problem**

Inadequately or poorly designed environments and tools of daily living continue to impose barriers to the individual with a disability. This issue needs to be addressed in order for people with disabilities to lead full and purposeful lives. To accomplish this goal it is imperative that designers of environments and artifacts have an in-depth knowledge of human functioning in the performance of tasks and problem-solving strategies to develop environments and products that best accommodate performance of these tasks. They require an understanding and useful characterizations of the abilities of people with disabilities and relevant mechanisms to incorporate this into a modern design process.

**Development**

The last few years have seen a dramatic increase in Digital Human Modeling (DHM) capabilities. This technology can provide designers and clinicians the human factors tools needed in the design process. It holds the promise of allowing qualitative pre-visualization and quantitative analysis, as well as dynamic simulation, of the ergonomic relationships between humans and the products they utilize and environments they inhabit - before the products are manufactured or the environments constructed.

Preliminary work done by these researchers has demonstrated the ability to create useful DHM visualizations of individual people with disabilities, based upon simple measurements of limb segment length and maximum joint angles. [Miller and Wang, 2001]

This effort to improve and utilize DHM technology for design purposes is important to designers and people with disabilities for two key reasons:

1. The design process is, by nature, time-intensive, non-linear and iterative which means that any pressure, such as lack of necessary information, time schedule or financial exigency will short circuit the process and lead to an incomplete or poorly designed product. The nature and extent of inadequately designed resources is experienced daily by every living person. The serious lack of designer-oriented computer-based anthropometric data for use in three-dimensional computer graphics software, has perpetuated the creation of inferior products and environments.
2. Popular business opinion often considers assistive technology for people with disabilities to be a 'limited market'. [NCDDR web site , 2001] This has led to the relegation of assistive technology and universal products and environments, which are useful to people with disabilities into a category called 'orphan technologies'. This term is applied because of a perception of limited markets for such products. [NCDDR web site , 2001] A shift in that perception could be achieved by the wide availability of designer-oriented DHM software coupled with the spread of Universal Design practices and the recognition that the market for universally designed products is a significant economic opportunity.

This project is developing a Functional Visualization System (FVS) for the development of Digital Human Models of people with disabilities for use by designers and clinicians. The proposed activities will lead to improvements in the design and usability of environments and artifacts used by people with disabilities.

Three distinct projects will be completed that demonstrate the use for the FVS and emphasize the development of the DHM visualization tools:

1. A *clinical prototype product*, which will demonstrate the usefulness of the FVS for clinical practitioners in the creation of mobility aids
2. An *environmental modification* project will carry out an intervention to improve a user-determined aspect of an existing residence
3. A *commercially viable* consumer product, which serves an existing need.

In general terms the process involves the capture of anthropometric measurements from individuals related to upper body segments and active joint range of motion.

These measurements are used in MIRAI, a 3D modeling and animation software package, to create motion visualizations and data sets of coordinate triplets based partly on traditional anthropometric measurements techniques and partly on basic repeatable movements that the participants can perform.

Participants will then re-enact specific movements, that have been animated in MIRAI, while in the CAVE (a virtual reality room that includes a motion tracking system), which can provide a precise digital trail of motion such as the location of the hand, elbow or shoulder during different sample runs.

The two forms of data, DHM and sensor/cave data can then be contrasted and compared to validate the accuracy of the DHM models in representing the functionality of the sample population of persons with disabilities.

The sensor data can be used to refine the DHM model or suggest ways in which the DHM model is inadequate for characterizing the upper body movements of people with disabilities.

Preliminary research has already created new context specific three-dimensional objects that represent the anthropometric functions of a person. These can be used by designers in many ways: They can be used as jigs, can help provide line of sight measurements and illustrate relationships with products or environments. They can provide the beginning outline of form a new product might take - or show the area that a product must reach in order to be useful. These objects go far beyond the placement of a static manikin in an environment and they are superior to animations of motion that must be viewed time and again to remember specific aspects of a transaction or interaction.

Further development of the FVS continues in order for it to be of use in the design process. The software must be productized and more functionality created so that new project specific visualizations needs can be quickly produced and tested through use by designers.

## Discussion

The project's primary goal is to demonstrate a holistic approach to the generation of solutions to typical problems confronted by people with disabilities. The project is, by its very nature, multidisciplinary and broad in scope. Its results will provide a proof of concept demonstration that products and environments, which meet the needs of people with disabilities, can move out the realm of 'orphan technology'.

It is meeting this primary goal through the following objectives:

- documenting measurement techniques which can be employed in a systematic way to provide needed anthropometric data of people with disabilities
- validating the measurement process and data which has been collected
- providing innovative, useful and commercially viable visualization tools to designers and clinicians which can solve typical problems related to anthropometric concerns
- creating partnerships with the various user groups during the whole project, which will help evaluate, refine and replicate the project's main goal and specific objectives.

A novel problem-based approach is being used

1) identify typical life problems which will lead to
2) specific dynamic measurements which are used to create
3) helpful visualizations that are targeted to be of
4) direct use by designers.

This project will lead to outcomes of:

*processes* - how this project was conducted and how the visualization software is created and used, and

*product* - the software itself.

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# ASSISTIVE TECHNOLOGY OUTCOME ASSESSMENT PROTOTYPES: MEASURING "INGO" VARIABLES OF "OUTCOMES"

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## ABSTRACT

Measuring outcomes of assistive technology interventions has received significant recent attention including the funding of two new major research projects by NIDRR. However, the successful measurement of assistive technology is daunting. Fundamentally, it requires the clear identification of the types and nature of assistive technology devices and services provided. Furthermore, assistive technology interventions must be isolated from a number of other concurrent rehabilitation and educational interventions if we are to understand the true impact of the assistive technology. This is not an easy task. This paper describes two prototype methods we are developing to help identify and isolate assistive technology interventions from other interventions used simultaneously in the natural setting. These include an Assistive Technology Device and Service Inventory and an AT Isolation Model.

## BACKGROUND

NIDRR cites numerous reasons why attention to assistive technology outcomes is important at this time. Monetary expenditures have been key motivators for funding agencies and consumers who desire better outcomes of assistive technology. Additionally, outcomes are needed for the development and improvement of assistive technology devices. NIDRR also recognizes that outcomes can be measured on numerous levels and from many perspectives of various stakeholders. Unfortunately, assistive technology outcomes measurement has lagged behind outcomes study methodology in related fields.

Challenges in sound AT outcomes measurement are numerous. Among them is the diversity of populations for which outcomes of assistive technologies are relevant, as well as the wide variety of service settings and environments. Plus, the outcome model must keep the person at the center of the measurement, as opposed to a focus from a specific service, device or population perspective. Fortunately, some strategies from other fields such as decision analysis give us some new ways to think about outcomes measurement. While these have been cited previously as having potential (Smith, 1998) specific applications have been limited. Two strategies for new instrumentation relevant to assistive technology outcome presented here are grounded on the need to isolate AT intervention outcomes from the array of concurrent interventions.

## STATEMENT OF PROBLEM

The ATOMS project (Assistive Technology Outcomes Measurement System), one of the NIDRR funded AT outcomes research projects, has conceptualized the overall problem of Outcomes Measurements as depicted in Figure 1. What can be seen in this figure is that there are four major components of successful outcome measurements. These include: 1) understanding the **context** of the person requiring intervention, the tasks they are performing, and the environment in which they are participating, 2) assessing the performance or perceived performance of the individual as a **baseline**, 3) depicting the **interventions** for which we highlight that there are six, and 4) measuring the **outcome**. The "Intervention Approaches" component is often ignored in assistive technology outcomes measurement. If outcomes are the endpoint, then these might be called "ingo" variables. As shown in the figure, assistive technology devices are often accompanied

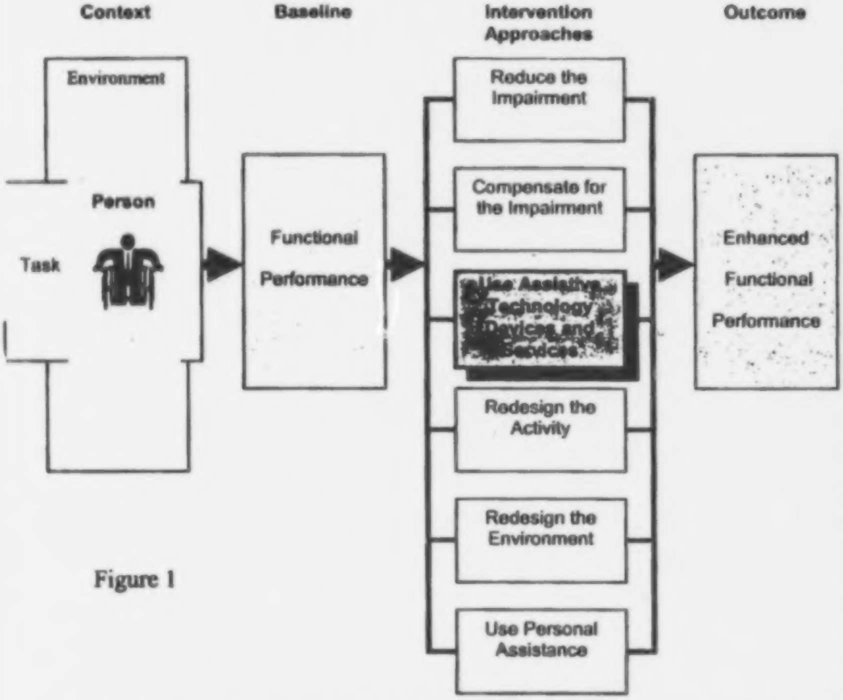
Context
Baseline
Intervention Approaches
Outcome
Environment
Person
Task
Functional Performance
Reduce the Impairment
Compensate for the Impairment
Use Assistive Technology Devices and Services
Redesign the Activity
Redesign the Environment
Use Personal Assistance
Enhanced Functional Performance

Figure 1

by assistive technology services. Therefore, in order to understand the outcome we must only know which devices and what services comprise the overall assistive technology intervention. Identifying the exact nature of the assistive technology intervention becomes its own data collection problem. Potentially, not only are there over 20,000 assistive technology devices and virtually countless permutations and combinations, but we also have potentially an infinite number of service models and strategies, team designs, and so on

Even more confounding is that assistive technology is only one intervention approach. Other valid interventions run concurrently with the application of assistive technology, including reducing the impairment, helping an individual compensate for the impairment, redesigning a task or an activity, redesigning the environment, or providing personal assistance. Each of these six approaches can be valid alone or in combinations. These have been highlighted as approaches used in rehabilitation for some time (Christiansen, 1991) and more recently (Smith, 2000).

## RATIONALE:

The ATOMS Project promotes the discussion of how to measure these "ingo" variables. Without some mechanism to isolate assistive technology devices and services as the specific intervention of interest, we may never obtain valid outcomes information specifically relevant to these interventions. The field of Decision Analysis provides some interesting possibilities and provokes the design and development of some new ways of identifying of "ingos" as the context for "outcomes".

## DESIGN & DEVELOPMENT:

Two specific instruments are described here. The first is an AT Device & Service Inventory. The second is an AT Approach Isolation Measure (subjective). Numerous outcome studies have needed to identify what assistive technology devices have been used and some description of their application. These range from checklists of assistive technology devices, categorization, and coding of devices. Past projects at UW-Milwaukee have also required the development of such inventories

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from which some redundancy across various populations and outcomes data collection has been observed. We believe a taxonomic set of categories can provide the foundation for a next generation AT Device & Service Inventory. To identify assistive technology services, we have a model emerging from our Project OATS (Outcomes of Assistive Technology in the Schools) that highlights a number of service variables including characteristics of an assistive technology team. These are presented as multiple-choice options with a fill in the blank option. Assistive technology device and service inventory forms are being collected and compiled to be made available for perusal, as well as to contribute to the next generation instruments under development.

The second instrument targets isolating the contribution of assistive technology from other concurrent interventions. This approach uses decision analysis modeling called MAU (Multi-Attribute Utility). A straw model following general steps outlined by Gustafson, Cats-Baril and Alemi (1992) generates a method to estimate the amount of contribution each of the six intervention approaches on a given outcome. In brief, the estimation process generates a set of scores, which looks similar to the first chart below. These scores can then normalized into percentages which can be used to weight the AT interventions as shown in the second chart.

| | |
|---|---|
| Reduce the impairment | 10 |
| Compensation for the impairment | 10 |
| Use of assistive technology | 50 |
| Redesign of the activity | 20 |
| Redesign of the environment | 15 |
| Use of personal assistance | 40 |
| Total contribution | 145 |

| | |
|---|---|
| Reduce the impairment | 6.9% |
| Compensation for the impairment | 6.9% |
| Use of assistive technology | 34.4% |
| Redesign of the activity | 13.8% |
| Redesign of the environment | 10.3% |
| Use of personal assistance | 27.6% |
| Total Contribution | 100% |

## DISCUSSION

These two prototypes based on previous models and instrumentation used in assistive technology and related fields, while these are innovative in terms of an overall assistive technology outcomes data collection process, these are viewed as essential components to an overall outcomes measurement system.

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## ACKNOWLEDGMENTS

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# MEASURING CONSEQUENTIAL VALIDITY OF AN ASSESSMENT INSTRUMENT USING HUMAN JUDGEMENT

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## ABSTRACT

Consequential validity is the evaluation of the intended and unintended social consequences of test interpretation. It is important that an assessment tool's consequential validity be tested as it allows the test user to know how confident she/he will be in making interpretations based on the score of the instrument. The method of measuring consequential validity is instrument specific. The consequential validity of SFA-AT has been measured in the past. The procedure of how to measure the consequential validity of WebAUDIT, a tool that uses human judgment, has been described. The methods of measurement of consequential validity of SFA-AT and WebAUDIT can be used as reference examples when implementing the procedures to measure the consequential validity of a tool that uses human judgment in measurement.

## BACKGROUND

Consequential validity is a kind of construct validity that is defined as the evaluation of the intended and unintended social values or consequences of test interpretation (1). It has also been defined as the validity of interpretations of a particular instrument (2). It is important to know the consequential validity of a measurement instrument as it allows the test user to know how confident she/he would be in making an interpretation based on the score from that instrument (3). Consequential validity is difficult concept to assess, as it is instrument and user specific. It is for this reason that it has not been measured until recently in occupational therapy. There has been a need for valid instruments that measure the person performance environment fit while assessing assistive technology outcomes and Web content accessibility. Both of these areas involve human judgment.

The reauthorization of the IDEA stimulated interests to find better methods to identify assistive technology services and measurement of assistive technology outcomes (4). A Wisconsin-based study investigated the consequential validity of the modification of the School Function Assessment (SFA), called the SFA-AT. The researchers examined whether the SFA-AT was more effective than the SFA in helping occupational and physical therapists assess assistive technology outcomes Twenty-eight therapists from Wisconsin trained in the SFA participated in the study. Therapists' wrote interpretations related to assistive technology outcomes based on case examples using either the SFA or the SFA-AT. These were compared to interpretations of the same cases made by an assistive technology expert panel. The therapists also completed a questionnaire asking how they felt about the overall quality of their interpretations (2).

There is need to measure Web content accessibility. Analysis of data from the Computer and Internet Use Supplement of Current Population Survey for December 1998 indicates that about half of the persons with disabilities have access to a computer and only about a quarter use it to connect it to the Internet (5). Section 508 of the Rehabilitation Act Amendments of 1998 mandates that any form of electronic information from a Federal agency be accessible to a person with a disability who may either be employed by the agency or be a member of the public wishing to access that information. Accessible Web content can be defined as the access of a website by dominant proportion of individuals with motor, sensory and cognitive disabilities. Various tools are currently available that try to measure Web accessibility but most of them do not incorporate human judgment components in these measurements. WebAUDIT (6), on the other hand, tries to measure these human factors. Tobianski conducted a study to find how WebAUDIT helps individuals not experienced in Web accessibility identify not only accessibility issues but issues that are considered more robust (7). The results of the study indicate that WebAUDIT might assist in one's ability to identify issues that prevent or inhibit access of information displayed in a Web page format. Tobianski's study leaves room for future reliability studies and further validation of WebAUDIT as an effective tool to measure Web content accessibility.

## RESEARCH QUESTION

The review of the literature suggests that there are no valid tools that measure Web content accessibility. The objective is to identify a method to measure the consequential validity of the WebAUDIT. Comparing the effectiveness of different resources in providing Web accessibility information can assist in this process.

## METHODS

The classical Multiple Group Pretest-Posttest Experimental Design can be used to measure the consequential validity of the WebAUDIT by studying the accessibility of ninety Occupational Therapy program websites (*see Appendix A for diagrammatic representation of the research design*). Initial accessibility of all the websites will be evaluated using the WebAUDIT. Thirty websites each will be randomly assigned to one of the three groups: Control Group, Web Accessibility Public Resource Group and WebAUDIT Group. Group-specific information, no information to the Control Group; list of four Web accessibility resources to Web Accessibility Public Resource Group; and a completed WebAUDIT review along with the list of four accessibility resources to the WebAUDIT Group, will be provided to the webmasters of the sites. After two months, the websites will be evaluated again to measure their accessibility using the WebAUDIT.

ANOVA methods can be used to compare the means of the accessibility scores assigned to the websites using the WebAUDIT. ANOVA would be used to prove that the three groups of websites are significantly similar before and significantly different after providing accessibility information. Three t-tests will be used to find whether the mean scores of the three groups changed significantly from the pre to the posttest.

## RESULTS AND DISCUSSION

Performing the above method will result in the measurement of consequential validity of an assessment tool that uses human judgment to measure the construct of Web accessibility. It will also result in tool whose reliability and validity has been measured. The above-mentioned method will also serve as an example of how to measure the consequential validity of an assessment tool.

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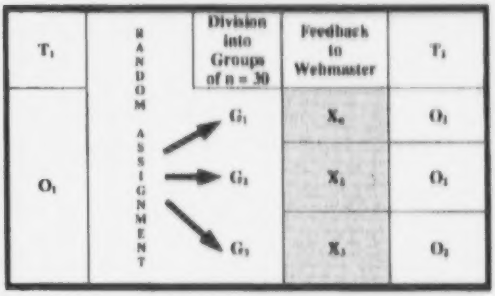
## APPENDIX A: RESEARCH DESIGN OF THE STUDY



**Key:**
$T_1$: First time observation of the websites.
$O_1$: **Pre-Test:** First observation of all the selected websites using WebAUDIT
$G_1$: **Control Group:** The group of websites that will not be provided with any kind of accessibility information until the end of the post-test.
$G_2$: **Web Accessibility Public Resources Group:** The experimental group that will be provided with accessibility information in the form of a resource list of various publicly available tools or guidelines on web accessibility.
$G_3$: **WebAUDIT Group:** The experimental group that will be provided with accessibility information in the form of a resource list, which is also provided to Web Accessibility Public Resource Group. and WebAUDIT assessment (see Appendix E).
$X_0$: No feedback given at all.
$X_2$: Accessibility feedback provided to the webmasters in the form of a resource list.
$X_3$: Accessibility feedback provided to the webmasters in the form of a resource list and the WebAUDIT review of their website.
$T_2$: Time approximately two months after $T_1$.
$O_2$: **Post-test:** Second measurement of accessibility of websites using WebAUDIT.

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# THE FUNCTIONAL EVALUATION IN A WHEELCHAIR (FEW) INSTRUMENT: TEST-RETEST RELIABILITY AND CROSS-VALIDATION WITH CONSUMER GOALS

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## ABSTRACT

The primary goal of this study is to develop and evaluate an outcome measure focusing on user ability to function while using a seating-mobility device. In Phase 1, the Functional Evaluation in a Wheelchair (FEW), Beta Version 1.0 was developed and validated. Phase 2 test-retest reliability of the FEW, Beta Version 1.0, and cross-validation of the FEW with consumer goals from four databases, are presented.

## BACKGROUND

In Phase 1, 10 FEW categories were developed based on responses from 20 manual and power wheelchair users (2), 17 of whom participated in the initial content validation study and then self-administered the FEW, Beta Version 1.0 (1). The Phase 1 findings indicated users had unmet needs affecting function, and supported further study and evaluation of the FEW as a dynamic indicator of perceived function relating to seating-mobility system use (2). The FEW, Beta Version 1.0 consists of 10 questions, scored on a 7-point ordinal scale, in the following format: My wheelchair/scooter allows me to ... easily (a) operate it, (b) transfer from surface to surface, (c) use accessories, (d) do tasks at different surface heights, (e) reach, (f) get around indoors, (g) get around outdoors, (h) ride public transportation, (i) secure it during transportation, and (j) stow it in a vehicle.

## RESEARCH QUESTION

The objectives for Phase 2 are to: (1) examine the test-retest reliability of the FEW, Beta Version 1.0, and (2) conduct cross-validation of the FEW items with consumer goals. Instrument reliability is necessary to establish the stability of the response variable over time. Cross-validating the FEW items with consumer goals from two research study databases and two clinical databases assesses the ability of the FEW to capture goals identified by consumers as most important for function in their seating-mobility systems.

## METHOD

### Test-Retest Reliability of FEW Beta Version, 1.0

Currently, 30 of the 40 total consumers have been recruited from the University of Pittsburgh Medical Center (UPMC), Center for Assistive Technology (CAT). The inclusion criteria were manual or power wheelchair users with a non-progressive condition (see Table 1). Trained researchers administered the FEW, Beta Version 1.0 at the center, and then users self-administered the FEW 4-7 days later and returned the instrument by mail. Data analyses were conducted using SPSS. Four consumers did not return the self-administered FEW, and were not included in data analyses.

### Cross-Validation of FEW Items

Four databases with consumer goals for seating-mobility technology were used to cross-validate the content of the FEW items: (1) internet-based (IB) study database, (2) telerehabilitation (TR) study database, (3) CAT medicalized (CAT-M) and (4) CAT consumer-reported (CAT-C) clinical databases. The IB study included 71 participants (see Table 1) from whom consumers' goals were collected from their pretest and posttest responses on a life goals questionnaire in the categories of mobility, self-care, productivity, and leisure after exposure to WheelchairNet, a website designed to inform consumers, clinicians and others regarding wheelchair use (3). Next, goals of 20 consumers (see Table 1) were collected from a TR study designed to establish a scientific basis for the reliable use and limits of video conferencing systems to evaluate the needs of wheelchair users. Four seating-mobility clinicians (two occupational therapists and two physical therapists) performed one in-person or TR mobility assessment for each consumer over a 3-7 day interval, for a total of 80 evaluations and sets of goals (4). Clinical records for seating-mobility clients (see Table 1) were systematically drawn from the CAT-M (every 10th record) and CAT-C (every 3rd record) clinical databases. Using a consensus approach, frequency data from each database were collected each

Table 1. Test-Retest and Cross-Validation Sample Demographics

| | Test-Retest | IB | TR | CAT-M | CAT-C |
|---|---|---|---|---|---|
| | n = 26 | n = 71 | n = 20 | n = 20 | n = 20 |
| **Age**<br>mean (min, max) | 45.54 (19, 67) | 42.66 (22, 63) | 42.20 (**) | 47.25 (31, 80) | 54.95 (20, 83) |
| **Gender** | M = 15<br>F = 11 | M = 35<br>F = 36 | M = 10<br>F = 10 | M = 11<br>F = 9 | M = 10<br>F = 10 |
| **Race** | White = 22<br>Black = 3<br>Asian = 1 | ** | ** | ** | ** |
| **Diagnosis** | (n=7) Cerebral Palsy (CP)<br>(n=6) Spinal Cord Injury (SCI)<br>(n=2) Spina Bifida (SB)<br>(n=11) Other diagnoses | (n=44) SCI<br>(n=10) CP<br>(n=4) SB<br>(n=3) Post Polio<br>(n=3) Arthritis<br>(n=7) Other diagnoses | (n=4) CP<br>(n=4) Head injury<br>(n=12) Other diagnoses | (n=4) CP<br>(n=2) Stroke<br>(n=2) Multiple Sclerosis (MS)<br>(n=12) Other diagnoses | (n=3) CP<br>(n=3) MS<br>(n=14) Other diagnoses |
| **Type of wheelchair (w/c)/ mobility device** | (n=16) Manual<br>(n=10) Power | (n=30) Manual<br>(n=24) Power<br>(n=16) Both<br>(n=1) Scooter | (n=13) Power<br>(n=7) Manual | (n=9) Manual<br>(n=5) Power<br>(n=5) Cane/walker<br>(n=1) Scooter | (n=13) Manual<br>(n=5) Power<br>(n-1) Scooter<br>(n=1) Walker |
| **Years of w/c use**<br>mean (min, max) | 19.76 (1, 52) | 18.68 (4, 52) | ** | ** | ** |
| **Age of w/c (years)**<br>mean (min, max) | 6.72 (6 months, 26) | ** | ** | 6.42 (1, 20) | 5.54 (1 month, 10) |

** Not included in database.

time a consumer goal was captured by a FEW item. A consumer goal reflecting more than one FEW item was coded for each item, as appropriate. For example, a goal for independent mobility in the home and community received a frequency code for the "operate my wheelchair," "indoor mobility," and "outdoor mobility" FEW items. If consumers' goals were not reflected in any FEW item, then a new category was added, ensuring that all consumers' goals were documented. Duplicate goals reported in a single medical record (i.e., CAT-M and CAT-C clinical databases) or at pretest and posttest (i.e., IB study) were coded only once. The results of the cross-validation of the FEW items and consumer goals will be used to examine the strength of the FEW items and identify new content items to be included in the FEW, Beta Version 2.0.

## RESULTS

The test-retest reliability results yielded an ICC $(2,k) = 0.94$, [CI = .84, .97; $p < .001$]. The cross-validation results are included in Table 2 for the four databases, with the 10 FEW items and additional categories not reflected in the FEW, Beta Version 1.0. The titles of the 10 FEW items and the 15 new categories were shortened in the table.

Table 2. Frequency of Consumer Goals with the FEW Items and New Categories in Four Samples

| FEW, BETA VERSION 1.0 ITEMS | | | | | | | | | | | | NEW CATEGORIES | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Operate wheelchair (w/c) | Transfer | Accessories | Surface height access | Reach | Indoor mobility | Outdoor mobility | Public transportation (trans.) | Secure w/c for trans. | Stow w/c for trans. | # Captured by FEW | W/C comfort | Drive from w/c/ adaptive controls | Personal self-care in w/c | W/C caregivers can operate | W/C reliability/ maintenance | Steps | W/C safety | W/C fit/accommodation* | W/C aesthetics | W/C efficiency | W/C features* | Pressure distribution | Postural control | Increase independence in self-care | Increase sitting time & tolerance | # Not captured by FEW | Total Goals |
| IB | 59 | 40 | 15 | 39 | 40 | 44 | 56 | 27 | 13 | 21 | 354 | 25 | 6 | 12 | 2 | 15 | 5 | 17 | 5 | 3 | 5 | 0 | 0 | 0 | 0 | 0 | 95 | 449 |
| TR | 80 | 15 | 37 | 2 | 2 | 29 | 40 | 8 | 16 | 22 | 251 | 22 | 0 | 0 | 0 | 3 | 1 | 5 | 75 | 0 | 0 | 193 | 0 | 0 | 0 | 0 | 299 | 550 |
| CAT-M | 16 | 12 | 10 | 7 | 9 | 17 | 15 | 10 | 13 | 11 | 120 | 12 | 0 | 4 | 6 | 16 | 1 | 18 | 13 | 0 | 0 | 19 | 12 | 18 | 0 | 0 | 119 | 239 |
| CAT-C | 15 | 1 | 0 | 2 | 2 | 17 | 12 | 0 | 2 | 1 | 52 | 7 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 0 | 1 | 6 | 3 | 5 | 8 | 3 | 44 | 96 |

* New categories captured in FEW, Beta Version 2.0.

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## DISCUSSION

The findings indicated that the FEW, Beta Version 1.0 was highly stable in its measurement of seating-mobility goals for Phase 2 participants over a one week interval. The cross-validation revealed the 10 FEW, Beta Version 1.0 items would have captured 79%, 46%, 50%, and 54% of consumers' goals in the IB, TR, CAT-M, and CAT-C samples, respectively. Although consumers in both the IB and TR samples rated the FEW item, operate w/c, as the top seating-mobility goal, no other FEW item or new category reflected a consistent pattern. Because of the pervasiveness of "w/c fit/accommodation" and "w/c feature" (see Table 2) goals identified by the TR and CAT-M samples, the FEW question format for Beta Version 2.0 will be revised to read: "My wheelchair/scooter features allow me to". If the wording for the Beta Version 2.0 had been in place and included these two categories as new items, the FEW would have captured 80% (354+5+0= 359/449= .80), 94% (251+75+193= 519/550= .94), 64% (120+13+19= 152/239= .64), and 61% (52+1+6= 59/96= .61) (see Table 2) of consumers' goals in the IB, TR, CAT-M, and CAT-C samples, respectively. Overall, the cross validation study yielded 15 new categories, not addressed in the FEW, Beta Version 1.0, for inclusion in FEW, Beta Version 2.0.

## SUMMARY

Test-retest reliability indicates that the FEW, Beta Version 1.0 was highly stable across time. Cross validation of the FEW, Beta Version 1.0 items with goals identified by four diverse samples of seating-mobility system users generated important new information regarding the ability of the FEW to identify users needs for appropriate seating-mobility technology. Additionally, the findings support the need to continue the cross-validation of the FEW using larger samples. The future research plans for this study include the development and validation of the FEW, Beta Version 2.0, and a clinical trial to determine the capability of the FEW to detect changes in function following acquisition of new seating-mobility technology.

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# THE APPLICATION OF OPTICAL SENSORS FOR QUANTIFYING ELECTRIC POWERED WHEELCHAIR DRIVING SKILL

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## ABSTRACT

Precision driving is an important factor for successful operation of an electric powered wheelchair (EPW). Using Fitts' law target acquisition parameters, we mounted four optical sensors on a test EPW to detect when it is positioned over a designated target. When provided with an integrated light source to prevent false triggering by shadows, optical sensors can reliably detect light or dark markers on a floor surface. This technology offers an inexpensive means to detect and quantify EPW position during research studies and has potential application for clinical evaluation and shared navigation systems.

## BACKGROUND

Fehr et al in a recently published survey (1) concluded that, as many as 40% of people who sought powered mobility could not be accommodated. They were unable to drive an electric powered wheelchair (EPW) safely or accurately with existing commercial controls. The Human Engineering Research Laboratories (HERL) has carried out multiple studies on control systems to improve EPW driving particularly for individuals with impaired upper extremity function. (2,3)

## STATEMENT OF THE PROBLEM

One of the challenges of evaluating EPW driving is objectively measuring driving precision. In clinical settings, a therapist will typically employ visual observation as a patient drives an EPW around a clinic floor space. Visual observation lacks quantification, which can make it difficult to determine which EPW or control interface best serves the patient. This imprecision can compromise securing third party funding in a health care system that continues to gravitate towards an "outcomes measures" philosophy for equipment purchase decisions.

EPW driving precision has been measured in past research by mounting a metal pole on the back of the test EPW and attaching a video camera in a "lookdown" position. The desired driving path is laid out with 2" wide paper tape with black numbers and tick marks. The resulting videotape provides a continuous quantifiable record of the chair position relative to the paper track over time. While effective, this technology is cumbersome to setup and labor intensive because the individual video frames must be digitized with human oversight to make certain the digitizing software picks up the correct markers. In preparation for a current study we chose to try mounted optical sensors to detect the EPW position rather than video tracking.

## RATIONALE

Fitts' law (4) relates the difficulty of a movement task to the width of the target and the distance between the start point and the target. Fitts' law has been successfully applied to many aimed human movements. Based on Fitts' law once a distance and target size have been selected, it should be possible to compare two different wheelchair controls by measuring just two parameters: the travel time from start-point to target (speed) and whether the subject is able to remain within the confines of the target upon arrival (accuracy).

## OPTICAL SENSORS

### DESIGN

The driving task is illustrated in figure one. A subject begin at the start circle and drives to the center of one of nine designated targets each target is driven to three times for a total of 27 trials. Each subject performs 27 trials with an isometric joystick, and an additional 27 trials with a conventional, movement-sensing joystick. The order of joystick presentation is randomized. The targets are black, vinyl-impregnated fabric disks (weatherproof tarp) 152 cm in diameter adhered to the floor with double sided tape. Data are collected with a laptop computer mounted to the rear of the EPW. The Joystick input is captured at a rate of 114 Hertz. Optical sensors are used to detect if the entire wheelchair is within the circumference of the target.

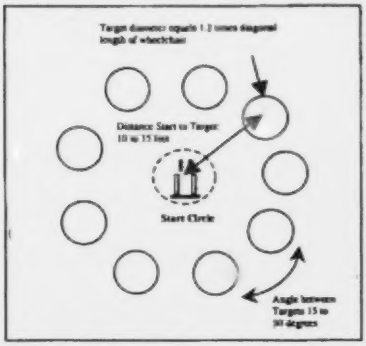
Target diameter equals 1.2 times diagonal length of wheelchair
Distance Start to Target: 10 to 15 feet
Start Circle
Angle between Targets 15 to 30 degrees

Figure 1. Methodology for Fitts' law EPW Research

### DEVELOPMENT

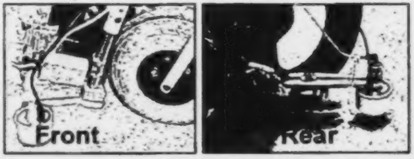

Figure 2. Sensor mounting

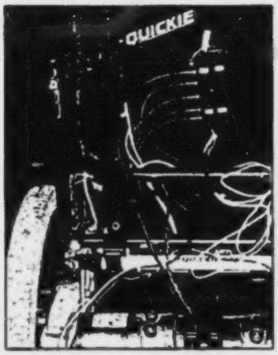

Figure 3. Interface box. LED's display sensor status.

We devised fixtures to position a phototransistor on each of the four corners of our test EPW. A fixture was place under the forward edge of each footrest and attached to the anti-tipper support tube behind the left and right rear wheels. The sides and top of the phototransistors were encased in black shrink wrap to block extraneous light and then inserted inside drilled out, tem cm lengths of 13 mm diameter, nylon threaded rod. By tapping a matching thread on the support fixture, the nylon rod could be rotated allowing us to precisely set the phototransistor height above the floor. (See Figure 2) A round, sub mini connector allowed the nylon rod to be adjusted without removing or twisting the interface cable. A project box mounted on the seat back housed the electronic needed to process the sensor status.(Figure3) Each phototransistor was placed in series with a 1 M ohm resistor using a five volt source. This voltage divider produced an output signal that increased as the phototransistor was exposed to progressively lower light levels. A comparator was used to compare this voltage to a reference voltage. When the output signal exceeded the reference, a digital high was delivered by the comparator to a quad, two-input AND gate. By successively ANDing the four phototransistors, a single high output was sent to our data computer when all of the phototransistor "saw" dark. In our initial trials, we observed that shadows cast by the EPW could falsely trigger our sensors as the EPW changed directions beneath the ambient room light. We corrected this problem by mounting incandescent light sources above the sensors, which effectively negated the shadows.

To pass our sensor status to our data recording laptop computer, we needed to place this status data on one of the computer's input ports, normally done with the serial or parallel port. Our serial port was occupied with data transmitted from the joystick control and our C++ development software did not provide a function to directly read the parallel port. A low cost ($10) PC keyboard was utilized. The keyboard chip was removed and our sensors' AND gate output wired to the keyboard chip pins associated with reading the "Shift" key. Using this hardware bridge resulted in a "Shift Key Down" event being sent whenever all four sensors were over the target, a "Shift Key Down" event can be easily detected by C++ code. If a "Shift Key Up" event, occurred immediately following a "Shift Key Down", we knew that a subject first drove over and then past the target with one or more sensors leaving the target.

## EVALUATION

An unimpaired operator has successfully generated several data files while piloting the test EPW. The data collection software can collect up to two minutes of data. When the software detects the "Shift Key Down" event; it aborts the two-minute data collection (saving the data already captured) and switches to a subroutine that collects data for a final two-seconds. If the Shift status remains set during these two seconds, the subject is assumed to have acquired the target and the trial scored as a "hit". If the Shift status is released before the two seconds expire, one or more of the sensors has passed out of the target circle and the trial will be scored as a "miss". The outcome of the trial, hit or miss, is appended to the data file before it is saved.

## DISCUSSION

Optical sensors offer an inexpensive means to detect the position of an EPW while maneuvering. The use of contrasting markers on a driving surface can be used in a variety of settings ranging from our basic target acquisition detection to more sophisticated applications. For example, in an EPW clinic, a driving course could be laid out with black duct tape on a lighter colored floor. Subjects could drive the course and be scored based by the number of times they crossed over the course boundaries. In a group home environment, contrast tiling could be used near the walls of a corridor. Individuals with marginal driving skills could be inhibited from hitting walls while still being free to drive independently.

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# Seating and Mobility
(Topic 8)

# ASSESSING THE INFLUENCE OF ASSISTIVE TECHNOLOGY ON PARTICIPATION

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## ABSTRACT

Full participation in major life activities is the goal of the Americans with Disabilities Act. Assistive technology devices clearly improve the lives of people with disabilities. Yet, measures of the effectiveness of assistive technology to improve activities of people with disabilities has been restricted to changes in the level of performing personal care and other activities presumed to have a relationship to the health of the assistive technology user. Moving to a measure of the influence of assistive technologies on participation in major life activities will provide a broader understanding of the effects of assistive technology on the lives of people with disabilities.

## INTRODUCTION

In the second part of the 20th Century, people with chronic diseases, serious injury and significant birth, structural and functional differences have survived in greater numbers, and are living with varying degrees of self-sufficiency, satisfaction and social support. These unexpected survivors have helped to advocate for new social policies that reflect their view that people with disabilities have the right to be included in American society as full and equal citizens. The Assistive Technology Act of 1998 described the need for assistive technology (AT) that enhances the ability of a person with a disability to engage in major life activities, beyond personal care and routine activities of daily living (1). The fundamental premise of the Americans with Disabilities act is that people with disabilities have the right to participate fully in all aspects of major life activities and to benefit from programs provided in the United States (2). Full participation in social activities rests upon making programs and physical structures accessible to people with disabilities. The degree of accessibility needed for full participation is inexorably linked to the limitations of the capacity, availability and effectiveness of AT. While the goals of the new legislation and the importance of AT to meeting the rights of the new survivors are clear, the links between legislative intent and enhanced participation based on assistive technology have not been made. The lack of a system to track these new survivors beyond acute medical care to reintegration into their community, presents a challenge to traditional concepts and measures used in health outcomes research. A review of the conceptual models and measures of disability shows a trend toward explicit inclusion of assistive technology. The changing scientific models and laws regarding people with disabilities provide impetus for the evolution of assessment tools to capture participation of people with disabilities in context of their communities.

Environmental factors, including assistive technologies have been integrated into several different models of disability(3). For example, the World Health Organization (WHO) has revised the original International Classification of Impairments, Disabilities and Handicaps, and has published a new version, International Classification of Function, Disability and Health (4) that includes the dimensions of body structures/functions, activities/participation and environmental factors. Environmental factors are an essential feature of the ICF system. The Products and Technology chapter has placed assistive technologies in sub-categories that include products for personal daily use, communication, personal mobility and education. The classification system details several sub-domains of activity/participation and environment, but no measures are tied to the classification system.

## MEASUREMENT OF DISABILITY

Traditional measures of treatment effectiveness have focused on narrow bands of activities and ignored the role of assistive technology. A frequently used measure, the FIM (Functional Independence Measure) assesses the level of independence in self-care, sphincter control, transfers, locomotion, communication and social cognition and is used in rehabilitation settings to evaluate patient progress and to predict the outcome of care. The activities covered by the FIM are limited in scope and do not cover independent community participation, although recent work by Stineman has proposed the inclusion of an environment tool kit to cover extrinsic factors that influence the expression of disability (5). Broad measures of health related quality of life (HRQOL) have been used to assess the status of people with disabilities as compared to healthy people. A frequently used assessment, the Medical Outcomes Standard Form–36 (6) includes questions on walking and climbing but does not include any provision for the use of AT to achieve the performance of activities considered to be essential to attaining a high quality of life. None of the functional measures of HRQOL assessment schemes have incorporated AT.

Research on the use of specific items of AT has been focused on consumer preferences (7) and on the use, disuse and abandonment of AT (8). These studies provide clear evidence that the fit between specific AT devices and the person's use of those AT devices is often incompatible. Clearly, evaluating the need for and the match of AT to individuals with disabilities is key to improving the efficient and frequent use of AT devices. Several books have devoted chapters to describing the steps necessary for service providers to take in selecting or recommending AT devices for their clients/consumers with disabilities (9,10). A relatively new measure, the Psychosocial Impact of Assistive Devices Scale (PIADS) is designed to measure the impact of one assistive technology device on the user's adaptability, competence and self-esteem (11). The PIADS provides a measure of consumer receptivity for specific devices but des not provide a measure for the broader influences of AT on participation by the consumer in a broad array of life activities. The need for outcome measures to capture the influence of the AT on the lives of individuals with disabilities is just beginning.

## MEASUREMENT OF PARTICIPATION AND ASSISTIVE TECHNOLOGY

The heterogeneity of people who use AT devices, the variety of activities, diversity of sites where AT devices is used and the vast array of different AT devices, make outcomes measurement difficult. While clinical evaluations of the person and devices match are necessary, they are not sufficient to predict the influence of AT devices on the lives of people with disabilities living in communities. To measure what social policies aim to change, the term 'participation' should to be incorporated into measurement tools. Glass (12) describes the doing of activities as participation. Our research has expanded the construct of participation to include temporal aspects of engaging in activities including frequency of doing activities (attending a sporting event) and preparation activities related to doing a more complex activity (e.g. dressing, transportation to the event). The construct of participation includes the individual's evaluation of the importance of doing the activity; the level of choice he/she has in doing the activity; and the satisfaction derived from doing the activity. Finally, participation requires the context of where and how activities are performed: personal assistance; assistive technologies; built environments; social; programmatic; financial; attitudes; and legislation.

Measuring participation as just described may be the key to escaping the trap of using the measures of physiological and mental function to justify payment for AT. A new survey, the PARTicipation Survey of Mobility limited individuals (PARTS/M), was developed to measure these aspects of the construct of participation. The environments of mobility-limited individuals are measured by a second new survey, Facilitators And Barriers to participation by Mobility-limited individuals (FABS/M). Both the PARTS/M and FABS/M are being used in longitudinal studies to track the use of AT devices and the level of participation of mobility-limited individuals in major life activities that are done in their homes and communities.

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# AN OBSTACLE COURSE FOR THE ASSESSMENT OF WHEELCHAIR MOBILITY PERFORMANCE

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## ABSTRACT

Factors that influence the wheelchair mobility performance may be the user's profile, the wheelchair, the environment, the daily activities and social roles, and the training. No existing assessment tool allows clinicians to evaluate wheelchair user mobility performance in an environmental situation which is potentially difficult and well-standardised. In response to that, this paper presents a new obstacle course assessment for wheelchair user mobility performance. It focuses on how the person is performing in terms of *time* (seconds) and *ease* (4 point scale) when moving through an obstacle course. Obstacles (3 inclines, 2 surfaces, 4 horizontal and 1 vertical obstacle) were designed and validated for their construct. This tool can be helpful for clinicians, researchers and designers.

## BACKGROUND

The main objective of wheelchair prescription is to select the wheelchair that allows the user to carry out his or her daily activities and social roles. A good matching between the person, the technology and the environment is essential (1). A poor evaluation of these factors will lead to unsatisfactory results in the wheelchair user's rehabilitation and mobility performance. The lack of standardised outcome measures has postponed the establishment of standardised and comparative data that could support and facilitate the work of therapists. Clinical tools used to select the appropriate wheelchair, to adapt the environment or to evaluate and train are not uniform. An outcome measure that would allow results to be evaluated and compared to standardised values is therefore necessary so that therapists can more effectively analyse clients' performance in the accomplishment of daily activities or social roles.

The evaluation of wheelchair mobility, be it powered or manual, requires a multifactorial approach. Main factors are the user's profile, the wheelchair, the environment, the daily activities and social roles the wheelchair user must complete, and the training received (2, 3). Theoretical or conceptual approaches, such as person-environment-technology models, the person-environment-occupation models and the disability creation process, support this affirmation. All those factors should be evaluated or documented to assess the wheelchair mobility performance (2). In a previous paper, authors suggested that literature yields three major categories of wheelchair performance or skills assessment tools: real environment assessment, controlled environment assessment and simulated environment assessment (2). The controlled environment assessment category, more specifically an obstacle course, seems to offer interesting possibilities and advantages. These include its ease of use in clinical settings, safety aspects, a reduced requirement for time and space as well as the opportunity to create a well standardised obstacle-laden environment, etc. (3, 4).

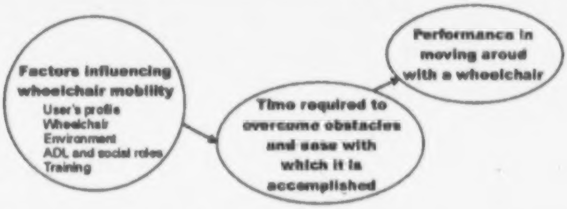
## OBJECTIVE

Because there is no assessment tool of wheelchair mobility performance taking into account all factors influencing wheelchair mobility, we propose to develop an obstacle course which allow to evaluate, in potentially difficult environmental situations, the wheelchair mobility performance required to complete daily activities and social roles, considering the user's profile, his or her wheelchair and the training received.

## APPROACH

***Conceptual and operational basis*** – Wheelchair performance is associated with beginning and carrying tasks through to completion, in moving around with a wheelchair. The performance can be measured by the time required and the ease with which one overcomes an obstacle. *Time* and *ease* are variables that can be influenced by the user's profile, wheelchair, environment, daily living activities and social roles and , training. Figure 1 illustrates the interaction between these concepts and represents the conceptual and operational basis for the proposed assessment tool.

Figure 1: Wheelchair performance in moving around with a wheelchair.


Factors influencing wheelchair mobility
User's profile
Wheelchair
Environment
ADL and social roles
Training
Time required to overcome obstacles and ease with which it is accomplished
Performance in moving aroud with a wheelchair

***Description of the tool*** – The proposed assessment tool is divided into two sections. The first section proposes to assess the wheelchair user moving on the obstacle course. It is composed of ten obstacles, divided into four categories which are well documented in the literature: incline, surface, horizontal and vertical obstacles (Table 1). The number of obstacles, their designs and their level of difficulty were selected based upon their difficulty and the frequency with which they were encountered in the execution of activities of daily living and social role. The content validation triangulates three data sources: opinion of experts (wheelchair users, occupational therapists and researchers), Canadian norms for home adaptation and the literature. For the scoring, *time* between the departure and the completion of the obstacle is taken with a stopwatch in seconds. *Ease* is assessed with a four level scoring grid: total success, success with difficulty, partial failure and complete failure (Table 2). The guide details each level of ease for each obstacle. Length of time to administer this section is about 30 minutes. The other section of the assessment is a checklist and space for comments in order to document characteristics of the user's profile, the wheelchair, the environment and the daily activities and social roles of the wheelchair user being assessed. Between 15 and 30 minutes are needed to complete this second part. This information is useful to support clinical intervention and to interpret the performance score, according to the conceptual and operational basis presented in Figure 1.

## DISCUSSION

With this assessment, the wheelchair mobility performance can be measured through the completion of 10 obstacles in using a four level scoring grid and a stopwatch. A validity and reliability study is underway with different groups of wheelchair users: bimanual, one hand and foot, and motorized modes of propulsion. As a clinical tool, the new assessment provides data to help therapists choose the wheelchair for a specific individual, to modify his or her environment

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and to adapt his or her training. As a research tool, it can be helpful to evaluate the effect of different wheelchair configurations, environments or training protocols. Also, it can be used to study interactions between mobility performance and factors influencing it or interactions between different factors. For developers, this assessment tool could be helpful to meet users' needs in testing new products.

Table 1: Obstacles retained for the evaluation of wheelchair mobility performance.

| **Category of environmental situation** | **Circuit obstacle** |
|---|---|
| Going up and down an incline<br>(Incline) | 1. Going up and down a 6 m incline of 1:16<br>2. Going up and down a 6 m incline of 1:12<br>3. Going up and down a 6 m incline of 1:8 |
| Getting onto a sidewalk or over a doorway<br>(Horizontal obstacles) | 4. Getting onto a 17.5 cm (7 inch) sidewalk<br>5. Getting onto a 7.6 cm (3 inch) sidewalk<br>6. Getting over a 5 cm (2 inch) doorway<br>7. Getting over a 2.5 cm (1 inch) doorway |
| Driving and manoeuvring while avoiding vertical obstacles<br>(Vertical obstacles) | 8. Moving through a narrow corridor, negotiating through cones and passing through a doorway |
| Moving on different surfaces<br>(Surfaces) | 9. Moving on a carpet (quite thick and soft)<br>10. Moving on gravel 6 mm to 19 mm (¼ inch – ¾ inch) |

Table 2: Definitions of level the four level scoring grid.

| **Level of performance** | **Definition** |
|---|---|
| Total success | The obstacle is completely overcome, without difficulty, on the first attempt, in a safe manner, and as requested, that is to say as the wheelchair user being evaluated would do so in the context of his/her daily activities. |
| Success with difficulty | The obstacle is completely overcome, with difficulty or in an unsafe manner. Some adjustments were necessary. The user required two or three attempts. |
| Partial failure | The obstacle is partially overcome and not complete with major difficulties, in an unsafe manner or required many adjustments. The wheelchair user attempted 3 times and still did not succeed or was aided by another individual. |
| Complete failure | The wheelchair user refuses or is unable to overcome the obstacle alone. |

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# WHEELIE TRAINING: DOES ADDING THE PROACTIVE BALANCE STRATEGY IMPROVE OUTCOMES?

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## ABSTRACT

The wheelie is a useful wheelchair skill. The objective of this study was to test the hypothesis that wheelie training with a combination of conventional reactive balance strategy (RBS) and proactive balance strategy (PBS) elements decreases training time and increases the success rate, compared to RBS training alone. We randomly assigned 22 individuals to one of the two training groups. Subjects ranged in age from 19-68 yrs and 45% were able-bodied. Mean (SD) learning times were 33.3 (12.7) min for the RBS+PBS group and 36.1 (16.9) min for the RBS group ($p = 0.57$). The learning success rate was 100% for both groups. Qualitative force plate data suggest that the PBS+RBS subjects used lower frequency, higher amplitude perturbations to maintain balance than the RBS subjects. These findings have implications for wheelie training and for our understanding of the nature of this important wheelchair skill.

## BACKGROUND

Until recently, it has been assumed that the stationary wheelie is a skill that is best taught by instructing people to "react" to a loss of balance, moving the rear wheels in the direction of the tipping wheelchair (1,2) -- the reactive balance strategy (RBS). In an earlier study (3), we found that wheelchair users also appear to anticipate potential balance disturbances by using a "proactive" balance strategy (PBS). Using the PBS, wheelchair users appear to pre-empt loss of balance by increasing the functional base of support of the wheelchair. Although subjects in the earlier study were trained to perform the wheelie using only the RBS strategy, they all spontaneously adopted the PBS strategy.

## RESEARCH QUESTION

The purpose of this study was to test the hypothesis that, in comparison with the RBS alone, a training program designed to teach both the PBS and RBS would 1) decrease training time and 2) increase the success rate.

## METHODS

We studied 22 subjects (10 able-bodied, 12 wheelchair users) with mean (SD) age of 34.7 (14.7)yrs (range 19-68). Each subject was assigned, in a randomly balanced order, to either the RBS or the PBS+RBS groups. RBS subjects were instructed to react to a loss of balance by moving the rear wheels in the direction they were falling. The RBS+PBS subjects were instructed that, in addition to the RBS instructions, they should move the rear wheel gently back and forth to help prevent a loss of balance (3). Success at learning the wheelie was determined by the subjects' ability to perform 3

20-s wheelies in a row. They then performed 3 20-s wheelies on a force platform (4). A 2x2 ANOVA (with age as a covariate) was used to determine if differences in training time existed between training groups or between diagnostic groups (wheelchair users vs able-bodied). We used regression analysis to test the relationship between age and training time. Statistical significance was defined as $p<0.0125$.

## RESULTS

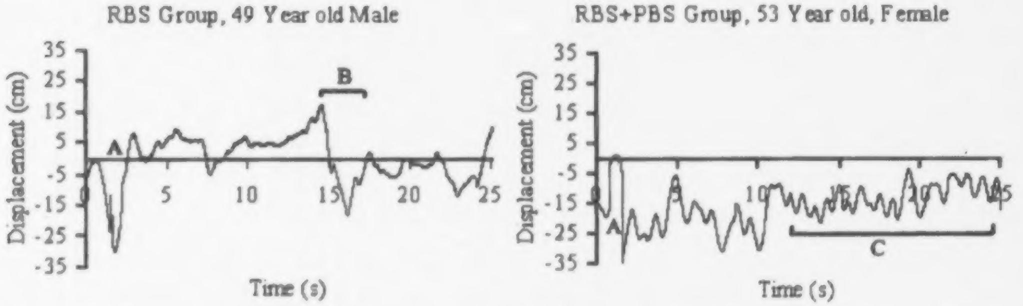
Subjects attended a mean (SD) of 2.4 (2.0) training sessions lasting 20.1 (5.2) min each, for a total training time of 43.9 (29.0) min. Success rate was 100% for both training groups. Summary data are presented in Table 1.

**Table 1: Summary data for the sub-groups of all 22 subjects.**

| | n | Age (years)* | Total Training Time (minutes)* |
|---|---|---|---|
| All Subjects | 22 | 34.7 (14.7) | 43.9 (28.9) |
| RBS | 11 | 36.1 (16.9) | 42.5 (31.4) |
| PBS+RBS | 11 | 33.3 (12.7) | 45.3 (27.8) |
| Able-Bodied | 10 | 23.9 (4.5) | 23.1 (8.6) |
| Wheelchair Users | 12 | 47.3 (14.2) | 61.3 (28.6) |

*Values quoted are mean (SD) for each group.

There was no significant difference between the training time for the RBS and PBS+RBS training groups ($p=0.57$) or between wheelchair users and able-bodied individuals ($p=0.14$). There was a relationship between training time and age ($r=0.7$, $p<0.001$). Qualitative observations from the force plate data suggest that RBS-trained subjects performed wheelies with high frequency, low amplitude movements, compared to the low frequency, larger amplitude RBS+PBS movements (Figure 1). In many cases, both groups exhibited both PBS and the RBS component within a trial


RBS Group, 49 Year old Male

RBS+PBS Group, 53 Year old, Female

**Figure 1:** Center of pressure movement of the wheelchair. Increase in value indicates a forward movement of the wheelchair. (A) Take-off, (B) RBS Episode, (C) PBS Episode.

## DISCUSSION

Adding a PBS component to conventional RBS training had no effect on training time or success rate. Because it is often believed that the wheelie is a skill that only young individuals are able to learn, the 100% success rate for both groups was surprising. Results also suggest that wheelchair users and able-bodied individuals of comparable ages require a similar amount of training. Although older adults require more training time, many can learn to perform a wheelie safely.

Many subjects found the wheelie training fatiguing, especially early in training. As training progressed, all subjects agreed that fatigue was no longer an issue. This was most likely due to the fact that, early in training, subjects tended to rely on strength to pop and maintain the wheelie. As they progressed, they learned to coordinate their movements and relied less on forceful movements. In the future, it may be useful to evaluate the energetic requirements of wheelie training to provide more insights into the safety of training older adults. From the force plate data, it appears as though subjects demonstrate somewhat different balance patterns depending on the training that they received.

Although the addition of the PBS did not affect the training time or success rate, our findings strengthen the argument for teaching advanced wheelchair skills to older wheelchair users. Older adults trained to use the proper techniques should be able to safely perform advanced skills such as the wheelie. These findings have implications for wheelie training and for our understanding of the nature of this important wheelchair skill.

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# EDUCATING STUDENTS OF OCCUPATIONAL THERAPY ABOUT WHEELCHAIR USE: COMPARISON BETWEEN STANDARD CURRICULUM AND SKILL-ACQUISITION PROTOCOLS

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## ABSTRACT

The objective of this study was to test the hypothesis that a formalized period of wheelchair skills training would improve the wheelchair skills of undergraduate students of occupational therapy. We randomly allocated 44 second-year students into either the Wheelchair Skills Training Program (WSTP) or Control groups. Both groups were pre-and post-tested with the Wheelchair Skills Test (*WST*). The WSTP group received 2.5-3hrs of wheelchair skills training in a workshop-like setting. Students in the WSTP group increased their mean (SD) percentage *WST* scores from 64.9 (8.9)% to 80.9 (5.2)%, a 24.7% improvement ($p = 0.000$), whereas those in the Control group increased from 66.1 (8.0)% to 72.4 (6.9)%, a 9.5% improvement ($p = 0.02$). The WSTP group improved to a significantly greater extent ($p = 0.004$). These findings have implications for the education of rehabilitation clinicians.

## BACKGROUND

As the prevalence and complexity of wheelchairs have increased, so has the need for improved training of occupational therapists (1). Although governing boards have introduced training competencies, specific training guidelines have been slow to follow (2). Some occupational therapy programs have adopted wheelchair experience exercises as their method of raising awareness of the potential role that mobility technology can play in lives of people with disabilities (3). While these exercises have been shown to raise student awareness, little is known about the impact that such exercises or other approaches have on the development of wheelchair skills and teaching abilities (4). To gain further information about the current wheelchair-related curricula of occupational therapy programs, we sent an 11-item questionnaire to 150 schools of Occupational Therapy across North America. The majority of the 65 respondents indicated a need for improved wheelchair skills training in occupational therapy programs.

## RESEARCH QUESTION

The purpose of this study was to test the hypothesis that a brief formalized period of wheelchair skills training results in significantly greater improvements in wheelchair skills than a standard undergraduate occupational therapy curriculum that does not include such training.

## METHODS

We studied 44 second-year students of Dalhousie University's Undergraduate Occupational Therapy Program with their informed consent. They had not received any formal wheelchair skills training prior to the initiation of this study. Subjects were asked a series of questions pertaining to their previous wheelchair experience (e.g. work, Special Olympics). The subjects were fitted with one of three manual wheelchairs, based on their size. The armrests and footrests were then adjusted to ensure an appropriate fit. The subjects were randomly allocated into two groups of 22 students, the Wheelchair Skills Training Program (WSTP) and Control groups. All subjects then performed the Wheelchair Skills Test (*WST* Version 2.4) that includes 24 groups of skills ranging from simple tasks such as brake application to ascending ramps and curbs, propulsion over gravel and wheelies (5). A percentage score was calculated based on the number of skills successfully executed.

Subjects in the WSTP group were then trained, in groups of two or three in a workshop-like setting (2.5-3hrs), on the skills that make up the *WST*. The subjects watched brief demonstration videos on how to safely and effectively perform all of the skills included in the *WST*. The students then took turns practicing and observing the skills in a random order. The wheelie was practiced in a blocked fashion due to the nature of the skill. Students in both groups got the formal wheelchair training of the Dalhousie curriculum between the pre- and post-test. The Dalhousie curriculum consisted of a series of lectures on wheelchair prescription, parts and maintenance. In addition, the students were required to spend 4 hours in a wheelchair. Following the training and control periods, subjects from both groups completed a post-training *WST* and follow-up questionnaire.

Differences in the *WST* scores between the pre- and post-training evaluations as well as between the WSTP and Control group percentage scores were compared using two sample t-tests. The level of significance used in all statistical analyses was $\alpha = .05$.

## RESULTS

There were 4 drop-outs from the Control group. The pre-training *WST* scores of the WSTP and Control groups were not significantly different ($p = 0.66$). Students in the WSTP group increased their mean (SD) percentage *WST* scores from 64.9 (8.9)% to 80.9 (5.2)%, a 24.7% improvement ($p = 0.000$), whereas those in the Control group increased from 66.1 (8.0)% to 72.4 (6.9)%, a 9.5% improvement ($p = 0.02$). The WSTP group improved to a significantly greater extent ($p = 0.004$) (Fig. 1).

## DISCUSSION

The results of the study show that individuals in the WSTP group experienced greater improvements in their wheelchair skills than individuals in the Control group. This was demonstrated by the change in *WST* scores between the pre- and post-training evaluations. These findings may be attributed to improvements made with respect to individual skills. Subjects in the WSTP group were able to successfully perform skills such as transferring in and out of the wheelchair, folding and opening the wheelchair, propulsion over an irregular surface, ascending a small (3.8cm) curb and descending a large (18cm) curb. Subjects in the Control group did not perform these skills as consistently as those in the WSTP group.

It is hoped that the findings of this study will provide educators with the evidence that they need to include a formalized period of wheelchair skills training in the curricula of undergraduate programs of occupational therapy. This study also has implications for the education of other rehabilitation clinicians.

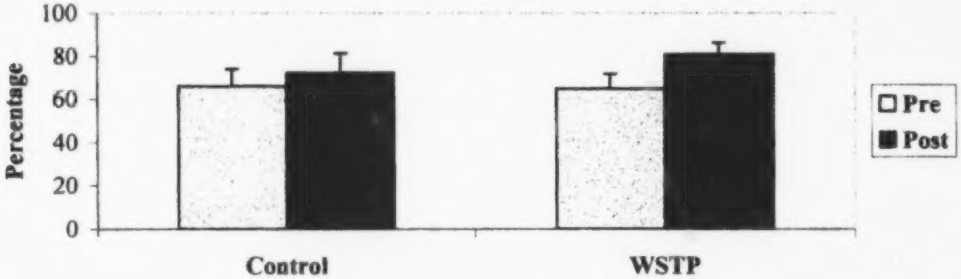

**Figure 1.** Mean pre- and post-training WST percentage scores for the WSTP and Control Groups.

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# DOES A BRIEF FORMALIZED PERIOD OF WHEELCHAIR SKILLS TRAINING IMPROVE OUTCOMES?

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## ABSTRACT

We tested the hypothesis that a brief additional period of wheelchair skills training would result in significantly greater improvements in wheelchair skills than a standard rehabilitation stay. Twenty-three new wheelchair users were assigned to the Wheelchair Skills Training Program (WSTP) or Control groups in a randomly balanced manner. Subjects were evaluated using the Wheelchair Skills Test (*WST*) on two occasions, between which the WSTP group received additional skills training. Although both groups improved significantly between evaluations (WSTP, p=0.00001; Control, p=0.03), the WSTP group improved [(post/pre x 100)-100] to a significantly greater extent (31%) than the Control group (8%) (p=0.0003). These findings provide support for the use of motor learning principles in a rehabilitation setting and have significant implications for wheelchair skills training.

## BACKGROUND

Wheelchair users frequently encounter physical barriers that prevent them from fully contributing to life within their communities (1,2). These barriers can also pose safety challenges (3,4). Eliminating architectural barriers is one approach to this problem. An alternative and complementary approach is to teach wheelchair users independent wheelchair skills. However, wheelchair skills training has received surprisingly little attention in the scientific literature.

## RESEARCH QUESTION

We hypothesized that a brief additional period of wheelchair skills training would result in significantly greater improvements in wheelchair skills than a standard rehabilitation program that did not include such training.

## METHODS

Twenty-three wheelchair users, admitted for initial rehabilitation, participated in this study. Subjects were allocated to the Wheelchair Skills Training Program (WSTP) or Control groups in a randomly balanced manner, with a comparable number of subjects using wheelchairs due to neurological and musculoskeletal disorders.

The skills set that subjects were tested and trained on came from the Wheelchair Skills Test (*WST*). The *WST* evaluates wheelchair-users' ability to perform 24 groups of skills required to overcome obstacles encountered in everyday life in a safe, controlled environment (5). For this study these skills were separated into four training levels ranging from easiest to most difficult.

Each subject completed a pre-training *WST* (version 2.4) evaluation within the first 10 days of admission to the Rehabilitation Centre, to serve as a baseline from which improvement could be measured. For the WSTP group, this evaluation also served to determine the training curriculum. Specifically, those skills not successfully completed during the pre-training *WST* were the focus of subsequent training sessions. Four weeks later, or before subjects were discharged from the Centre (whichever occurred first), subjects completed a post-training *WST*. Between these two evaluations, the WSTP group received additional wheelchair skills training as described below. The Control group did not receive any training beyond what was given within a typical rehabilitation stay.

Additional training consisted of a maximum of 6 30-min training sessions. Training began at the lowest appropriate level. For each level, subjects watched a video demonstrating various safe and effective ways to complete the skills before attempting them themselves. The first 20-min of each training session were dedicated to acquiring the new skills in the training curriculum. During this time, skills were practiced in a blocked fashion until successfully completed. Once given instructions, subject had two attempts to complete the task. If the skill was successfully completed during either attempt, training of the next appropriate skill began. If, however, the attempts proved to be unsuccessful, the subject received a knowledge-of-performance (KP) feedback statement focusing on the most critical error to be corrected. Providing feedback after two unsuccessful attempts (50% relative frequency) continued until the skill was completed successfully or abandoned. The last 10 min were used to practice (in a random order) successfully completed skills (including those completed during the pre-training *WST* evaluation). During this time, subjects received feedback only if they were unable to complete the skill, or if they completed the skill in an unsafe manner.

Once subjects had passed or abandoned all of the *WST* skills, subjects practiced all non-abandoned skills in a random order to end that session. Once these skills could been successfully completed within one training session, or six training sessions had been completed, training ended, and a retention test (post-training *WST* evaluation) was completed at least one week later. Paired t-tests and a two-sample t-test were used to compare the total percentage *WST* scores change within and between groups. A two-sample t-test was also used to determine the comparability of the two groups. For all tests, significance was determined at a $\alpha$ level of 0.05.

## RESULTS

Two-sample t-test results determined that there were no significant differences in the total percentage WST scores between groups at the initial evaluation. Both groups showed significant improvements in wheelchair skills from pre- to post-training *WST* evaluations (Figure 1). The control groups' average percentage score increased from 63.5% (±13.3) to 68.3% (±10.8) for an overall improvement of 8% ($p = 0.03$). The WSTP group increased from 60.1% (±9.2) to 78.5% (±4.6), improving 31% ($p = 0.00001$) after receiving an average of 5 (± 1.2) training sessions. The WSTP group showed significantly greater improvements in wheelchair skills than the control group ($p = 0.0003$).

## DISCUSSION

The brief period of additional wheelchair skills training that the WSTP group received resulted in significantly greater improvements in wheelchair skills compared to a standard rehabilitation stay

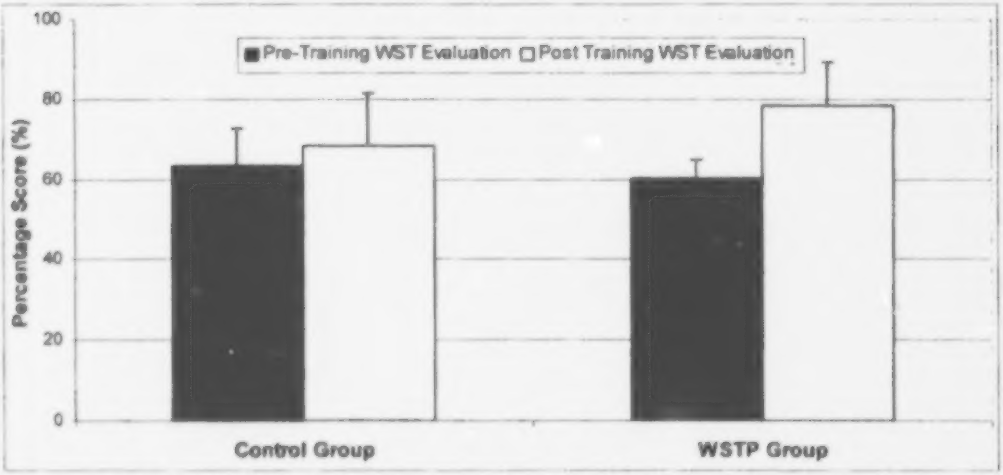

**Figure 1:** Wheelchair Skills Test (*WST*) Percentage Scores for Control and Wheelchair Skills Training Program (WSTP) groups at pre- and post-*WST* evaluations.

that did not include such training. With only 5 (± 1.2) 30-min training sessions, the WSTP group's improvement was almost 4 times that of the Control group. This study provides support for the utilization of common motor-learning principles in the rehabilitation setting and demonstrates how a relatively short period of additional training can have a clinically significant effect on new wheelchair users' independent mobility and quality of life. Increased wheelchair skills could decrease the frustrations experienced by wheelchair users, increase independent mobility through teaching obstacle-negotiating skills, and decrease the incidence of wheelchair-related injuries.

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# WHEELCHAIR SKILLS TRAINING: THE NEXT FRONTIER

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## ABSTRACT

Although there a number of resources and programs available that relate to wheelchair skills, there has been surprisingly little in the scientific literature that deals with the safety, effectiveness and efficiency of wheelchair-skills training. The objective of this paper is to briefly review our current status with respect to this issue and to suggest some directions for the future.

## BACKGROUND

The wheelchair, arguably the most important therapeutic tool in rehabilitation, has been the focus of extensive study. The role that individual wheelchair components, and how they are adjusted, play in wheelchair comfort, safety and performance has become well understood. In addition to research looking at the wheelchair itself, much is now known about the biomechanics of manual wheelchair propulsion and upper-limb ergonomics. Prescription of the most appropriate wheelchair for an individual and adjusting it properly are important elements in the wheelchair-provision process.

But, not all of the problems related to wheelchair use are exclusively due to the properties of the wheelchair and the user. The environment in which wheelchair users function is the third major factor affecting wheelchair safety and performance. Although awareness of the importance of architectural accessibility has improved, most wheelchair users still frequently encounter barriers such as curbs, steps, irregular surfaces and narrow doorways.

It is also becoming increasingly well recognized that there is still considerable room for improvement in the *training* of the wheelchair user in the safe use of the wheelchair in a variety of settings. The objective of this paper is to briefly review our current status with respect to this issue and to suggest some directions for the future.

## WHERE ARE WE NOW?

There are a number of excellent resources, in the form of textbook chapters and manuals (e.g., 1-3), for those involved in wheelchair-skills training. These are based on the extensive experience of clinicians and wheelchair users themselves. Many academic institutions include elements in their educational programs that relate to wheelchair skills (including a wheelchair experience, in many cases)(4). RESNA has taken a leadership role both by developing a program to certify the credentials of assistive technology providers and by regularly offering wheelchair-skills experiences at its annual meetings.

Despite these educational resources and efforts, there have been relatively few scientific studies on wheelchair-skills training. Bonaparte et al (5) have shown an example of how training related to one specific skill (the stationary wheelie) can be the subject of an in-depth evaluation of hypotheses about methods that might improve the effectiveness and efficiency of training.

We have developed (and are continuing to refine) a Wheelchair Skills Training Program (*WSTP*) for manual wheelchair users. This arose from the Wheelchair Skills Test (*WST*)(6), which is an integral part of the *WSTP*. The *WST* is an objective evaluation, in a standardized environment, of skills spanning the spectrum from those as basic as applying the brakes to those as difficult as climbing curbs and performing wheelies. The *WST* may be used early in the course of a rehabilitation program as a diagnostic measure to determine which (if any) skills need to be addressed during the rehabilitation process. The skills that have not been successfully performed, that have been performed in an unsafe way and that are appropriate goals for that wheelchair user in his/her expected environment become the *objectives* of the individualized *WSTP*. The ***curriculum*** consists of videotaped skill demonstrations, supervised practice and structured feedback. Repeating the *WST* on completion of the rehabilitation phase (or later during follow-up) constitutes the *evaluation* element in the educational process.

To date, MacPhee et al (7) have shown that the *WSTP* can be used to significantly enhance the wheelchair skills of inpatients in a rehabilitation center, in comparison with members of a control group who received conventional rehabilitation. Coolen et al (4) have shown that the *WSTP* can also be used, in a 2-3-hour workshop format, to improve the wheelchair skills of second-year occupational therapy students, in comparison with members of a control group who received only the conventional curriculum. One study is underway that utilizes aspects of the *WST* and *WSTP* to look at the wheelchair skills of caregiver-propelled user-occupied wheelchairs and another study is looking at subjects using pushrim-activated power-assisted wheelchairs (PAPAWs).

## WHAT DOES THE FUTURE HOLD?

There is a need for a wide-ranging series of studies relating to wheelchair skills training. In-depth analyses are needed for particularly difficult or dangerous skills (e.g., wheelies, curb ascent). Better wheelchair design (e.g., of armrests, rear antitip devices [8]) is needed to facilitate skill performance. The training programs may need to be adapted and validated for use by children or those with specific impairments (e.g., the neglect syndrome in people with hemiplegia). Such investigations are also needed with respect to powered mobility aids.

Principles that have long been recognized in the educational and motor-skills-learning worlds will need to be validated in, and adapted for, the wheelchair-skills domain. The trainers will need to be trained. Safety, efficacy and effectiveness are clearly important, but training protocols need also to be cost-efficient if they are to be widely utilized.

## CONCLUSION

In the current climate of emphasis on evidence-based and cost-effective practice, it has become increasingly important that rehabilitation practitioners be able to document the effects of their interventions. There is great theoretical potential for wheelchair training to improve safety and enhance the quality of life of wheelchair users, and there is some preliminary evidence to support the practicality, safety and efficacy of such programs. However, we will need to scientifically confirm these potential benefits and document their cost-efficiency if we are to successfully advocate for their widespread implementation.

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# WHEELCHAIR TIEDOWN LOADS AND OCCUPANT RESTRAINT LOADS ASSOCIATED WITH VARIOUS OCCUPANT SIZES IN FRONTAL IMPACT TESTING

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## BACKGROUND

The number of wheelchair users relying on public and private transportation has increased since the passage of the Americans with Disabilities Act (ADA). The number is expected to continue to increase due to improvement of access to work, public, and recreation areas. As evidence of increased number in private transportation, a survey conducted by National Highway Traffic Safety Administration (NHTSA) shows that the number of vehicles modified with adaptive equipment has greatly increased since the passage of the ADA.[1] According to the results of the survey, 42% of fifty-nine disabled participants had their vehicle modified for wheelchair securement (Table 1).[1]

*Table 1 Top Five Modifications/Adaptations in Use by Persons with Disabilities*

| Type of Modification | % Respondents Reporting Use (%) |
|---|---|
| Hand Control | 56 |
| Wheelchair Securement | 42 |
| Lift | 34 |
| Automatic Door Opener | 31 |
| Steering Control Device | 29 |

For the wheelchair users who are unable to transfer to vehicle seats, their wheelchairs must serve as vehicle seats. In order to provide protection for wheelchair occupants and other vehicle occupants, after market equipment is required to secure the wheelchair (WC) to the vehicle and restrain the WC occupant. *SAE J2249 – Wheelchair Tiedown and Occupant Restraint Systems (WTORS) for Use in Motor Vehicles* and *ISO 10542: Wheelchair Tiedown and Occupant Restraint Systems* specifies design requirements, test methods, and performance requirements for the aftermarket WTORS (1) (2).

Information related to WTORS loading under frontal impact can provide useful information for those designing transport-safe wheelchairs, adapted vehicles and WTORS systems. Since *ANSI/RESNA WC19 - Wheelchairs Used as Seats in Motor Vehicles* requires that transport WCs be equipped with securement points, tiedown loads or the loads applied to these securement points are key in the design of transport-safe WCs (3). Occupant restraint loads are also key to those intending to provide on-board or integrated WC restraints. To-date little information is available to guide manufacturers in the design of crashworthy pediatric products or products intended for use by small females.

## RESEARCH OBJECTIVE

The intent of this study is to summarize WTOR loading data during frontal impact sled testing for various size occupants. This data could be useful for those intending to design transport-safe products for various occupant sizes.

## METHODS

Thirty-six sled impact test reports from Convaid manufacturer were reviewed. In all tests, WC was secured to the sled platform using the surrogate four-point, strap-type tiedown. A six-year-old anthropomorphic test device (ATD) (21.8-30 kg), 5th percentile female ATD (45.5 kg), or 50th percentile male ATD (76.4 kg) was placed on a wheelchair and restrained by an independent surrogate three-point belt. The test was conducted under 20g/30mph frontal impact conditions.

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[1] http://www/nhtsa.dot.gov/cars/rules/adaptive

## RESULTS

The peak left-rear and right-rear tiedown strap loads are shown in Figure 1 for 6-year-old tests and Figure 2 for 5th %-tile female tests.

*Table 2 Summary of the peak left-rear and right-rear tiedown strap loads*

| | | Peak left-rear tiedown strap force, N | Peak right-rear tiedown strap force, N |
|---|---|---|---|
| 6-year-old | Max. | 5570 | 5028 |
| | Min. | 2849 | 2392 |
| | Ave. | 4152 | 3626 |
| 5th %-tile female | Max. | 5991 | 5451 |
| | Min. | 3806 | 3988 |
| | Ave. | 4958 | 4693 |
| 50th %-tile male | Max. | 7747 | 8084 |
| | Min. | 5498 | 4786 |
| | Ave. | 6393 | 5782 |

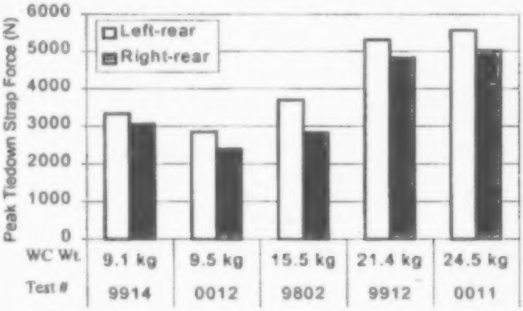

*Figure 1*
*Peak Tiedown Strap forces with 6-year-old ATD*

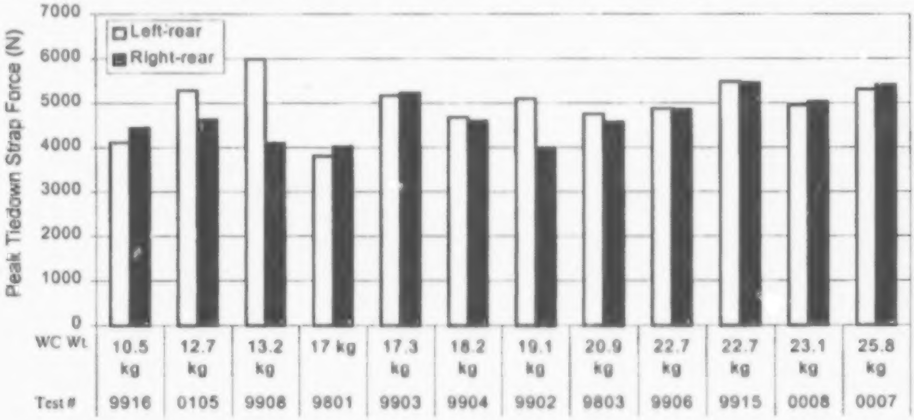

*Figure 2 Peak Tiedown Strap forces with 5th percentile female ATD*

The peak pelvic-belt and shoulder-belt loads are shown in Figure 3 for 6-year-old tests and Figure 4 for 5th %-tile female tests.

Peak tiedown strap forces associated with the 6-year-old ATD generally increase as the weight of wheelchair increases (Figure 1). All minimum, maximum, and average peak tiedown strap forces increase as the ATD size increases from 6-year-old to 5th percentile female to 50th percentile male (Table 2). Moreover, all tests showed higher shoulder belt loads than pelvic belt loads (Figure 3 and Figure 4). Pelvic belt and shoulder belt loads also increase as the ATD size increases from 6-year-old to 5th percentile female to 50th percentile male (Table 3).

## CONCLUSIONS

Wheelchair tiedown and occupant restraint loading data in thirty-six frontal impact sled test reports were analyzed. The average peak left-rear and right-rear tiedown strap loads were 3626N and 4958N for the 6-year-old ATD, 4693N and 6393N for the 5th %-tile female ATD, and 4693N and 6393N for the

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50th %-tile male ATD. The average peak pelvic-belt and shoulder-belt loads were 2538N and 3913N for the 6-year-old ATD, 3801N and 7018N for the 5th %-tile female ATD, and 6086N and 9634N for the 50th %-tile male ATD. The provided information could be useful for those designing transport-safe WCs and WTORS for various sizes of occupants.

*Table 3 Summary of the peak pelvic-belt and shoulder-belt loads*

| | | Peak pelvic-belt load, N | Peak shoulder-belt load, N |
|---|---|---|---|
| 6-year-old | Max. | 5355 | 5595 |
| | Min. | 1466 | 2080 |
| | Ave. | 2538 | 3913 |
| 5th %-tile female | Max. | 6750 | 8236 |
| | Min. | 1810 | 3965 |
| | Ave. | 3801 | 7018 |
| 50th %-tile male | Max. | 7397 | 11027 |
| | Min. | 4782 | 8536 |
| | Ave. | 6086 | 9634 |

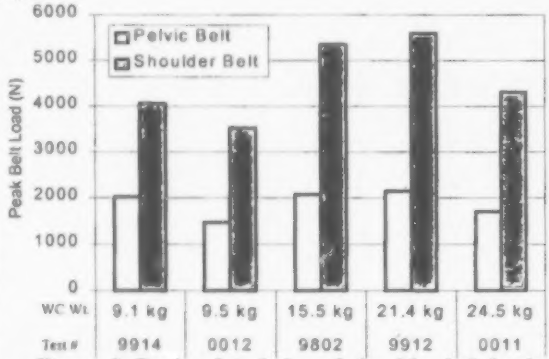

*Figure 3 Peak pelvic-belt and shoulder-belt loads with 6-year-old ATD*

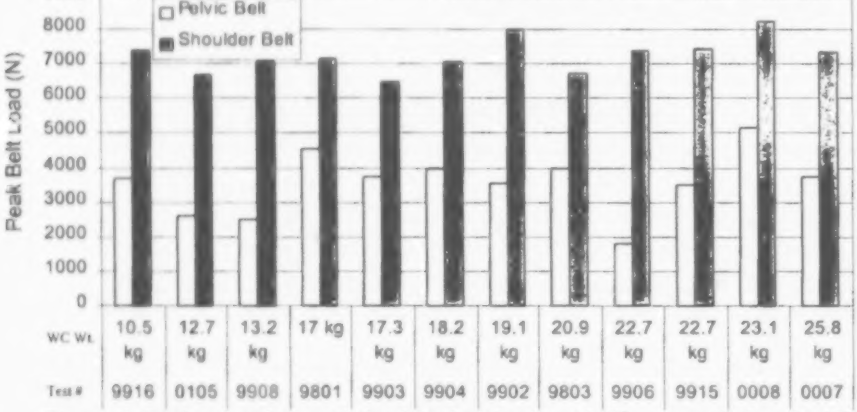

*Figure 4 Peak pelvic-belt and shoulder-belt loads with 5th percentile female ATD*

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# ISSUES RELATED TO THE LOCATION OF A UNIVERSAL INTERFACE FOR AUTOMATED WHEELCHAIR SECUREMENT

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## ABSTRACT

The industry standard for securing wheelchairs in motor vehicles is the four-point strap type tie-down system. These devices are time consuming to apply and require the assistance of the vehicle operator or an attendant. Therefore, many of the devices are either not used or are misapplied. Individuals using wheelchairs and transit organizations expressed interest in semi automated docking wheelchair securement. This type of securement system has the potential for decreasing the time needed to secure wheelchairs in motor vehicles. Most importantly, automated securement has the potential to drastically enhance the independence of wheelchair users seeking access to transport vehicles and therefore will likely increase the overall use and safety of wheelchair-seated passengers. A Universally Designed Interface Geometry (UDIG) is needed to ensure docking compatibility between the wheelchair and the securement device in the vehicle. To be successful, the UDIG, once agreed upon, needs to be adopted as a world-wide standard. This study addresses the issues related to defining the geometric and clear space specifications for a UDIG standard.

## BACKGROUND

While the four-point, strap-type tie-down system has been shown to be one of the most effective and versatile methods for securing a wide range of wheelchairs, it is also a system that is difficult and time consuming to use, creating logistical problems in the public-transit environment [1]. Additionally, laboratory tests have indicated that existing strap-type systems may be at the upper limits of their strength capacity when tested at the nominal 30 mph/20g crash pulse [2]. This implies that many heavier models of powered wheeled mobility devices (WMDs) may not be secure at the nominal crash load levels. ANSI/RESNA-SOWHAT, SAE Restraints Task Group and ISO-WG-6 standards development groups are now addressing many of these safety, incompatibility and inconvenience issues [3-5]. At the present time, standards development groups have completed the first stage of industry performance standards for transport WMDs and wheelchair (strap-type) tie-down and occupants restraint systems (WTORS). The term wheeled mobility devices, (WMDs) is used to mean wheelchairs (both manual and powered), scooters, and specialized seating bases, used by both adults and children. National and international standards development groups agreed to pursue the concept of a standard (universal) interface as being fundamental to the successful development and marketing of docking securement devices. Draft specifications for the geometry and a proposed Universal Device Interface Geometry (UDIG) standard were established. After considerable deliberation on alternate approaches to hardware configuration, a U-shaped tubular structure (adapter) mounted on the rear of WMD was deemed the most practical interface configuration (Figure 1). A remaining question is where the UDIG adaptor should be located in reference to some identifiable location on any WMD, and the required UDIG clearance zone to ensure access by vehicle-mounted docking securement

283

devices. Finally, the addition of the UDIG adapter should minimally increase the overall length of WMDs and not interfere with the feet or legs of attendants while propelling the WMDs.

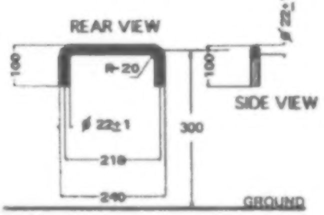


*Figure 1: UDIG dimensions (mm)*

## METHOD

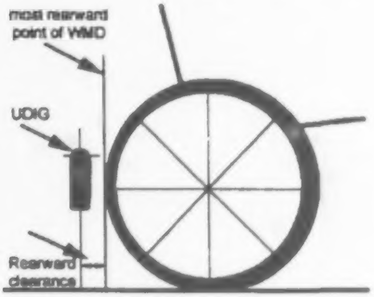
To determine the UDIG clearance zone and the UDIG location on various WMDs the following criteria were used:

- UDIG clear zone must be readily locatable on all WMDs (power, scooters, manual/ pediatric and adult)
- The clearance zone includes UDIG dimensions, its vertical location, plus a minimum of 25 mm clearance around the UDIG for docking engagement
- The UDIG clearance zone provides docking device access from both the rear and the rear floor areas
- The UDIG location must allow for leg clearance when pushing WMDs
- The UDIG locations should minimize any increase in overall length of WMD
- The UDIG locations should minimize any reduction to esthetics
- When conflicts arise assign priority to adult powered and attendant-propelled WMDs

In order to study UDIG location and clearance zone dimensions, a mockup of the UDIG was created to study location and UDIG clearance zones on different WMDs. Dimensions for clearance were measured from the most rearward point of the WMDs below a height of 300 mm. UDIG centerline dimensions were measured from most rearward to most inward the WMD footprint (Figure 2a and 2b). The WMDs and their UDIG clearance zones are listed in Table 1.

| Type WMD | Inward (mm) | Outward (mm) |
|---|---|---|
| Pride: Revo (scooter) | 0 | 0 |
| Espree Atlas (scooter) | 0 | 0 |
| Pride: 1113 Jazzy (power) | 0 | 16 |
| Invacare: Ranger X (power) | 0 | 31 |
| Quickie: S525 (power) | 40 | 36 |
| Quickie: S626 (power) | 32 | 36 |
| Permobil: Chairman (power) | 39 | 36 |
| Ottobock: Switch (manual) | 240 | 36 |
| Etac: (manual) | 350 | 36 |
| Invacare: Spider (manual) | 125 | 36 |
| Invacare: Action Orbit-tilt (manual pediatric) | 147 | 36 |
| Invacare: Action Orbit (manual pediatric) | 370 | 36 |

*Table 1: Evaluated WMDs and rearward and inward UDIG clearance spaces per WMD.*



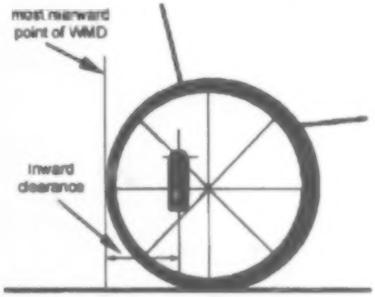
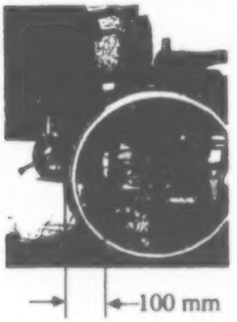


*Figure 2a (left): UDIG most rearward location (including 25 mm clearance), measured from the most rearward point of the WMD*
*Figure 2b (right): UDIG most inward location (including 25 mm clearance), measured from the most rearward point of the WMD*

Leg penetration with the wheelchair footprint was measured for various attendant propelled WMDs to evaluate UDIG-leg interference (Figure 3). An average leg-wheelchair footprint penetration of 100 mm was found for various wheelchairs.



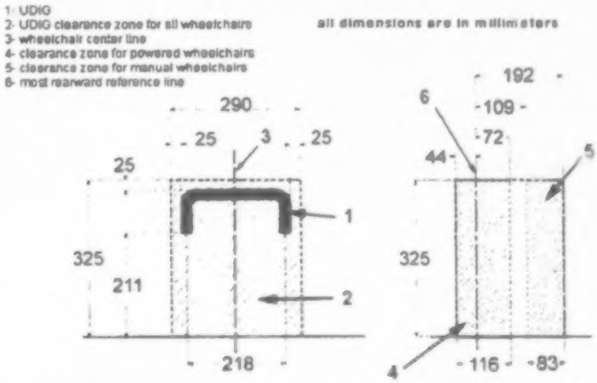

1- UDIG
2- UDIG clearance zone for all wheelchairs
3- wheelchair center line
4- clearance zone for powered wheelchairs
5- clearance zone for manual wheelchairs
6- most rearward reference line
all dimensions are in millimeters
290
25
3
25
25
1
325
211
2
218
192
6
109
72
44
5
325
4
116
83

*Figure 3: Leg-wheelchair footprint penetration during attendant wheelchair propulsion.*
*Figure 4: Proposed UDIG clearance zone for power/scooter and manual wheelchairs.*

## CONCLUSIONS

The previously developed UDIG was modified to better accomodate pediatric WMDs. The size (width) reduction was proposed based on the need to accommodate both pediatric and adult sized WMDs (Figure 1). UDIG clearance zones were found to be different for manual wheelchairs versus powered wheelchairs and scooters. Adding a UDIG to scooters will in most cases increase the length of the scooter. To prevent UDIG-leg interference with manual wheelchairs, the UDIG should be located 100mm inward from the most rearward point of the wheelchair. The findings in this study are preliminary and acceptance is pending the results from the ISO national voting process scheduled to conclude in Spring, 2002.

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## ACKNOWLEDGEMENTS

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# PROPULSION WORK AND POWER DIFFERENCES IN WHEELCHAIR USERS WITH GREATER EVIDENCE OF SHOULDER PATHOLOGY AT FOLLOW-UP

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## ABSTRACT

Biomechanical tests and magnetic resonance imaging (MRI) shoulder studies were performed twice, at baseline and after two years, on eight men and six women who used a manual wheelchair full-time due to spinal cord injury. Subjects were separated into two groups: seven subjects whose MRI injury scores had increased (MRI+) and seven subjects whose MRI scores remained the same or improved (MRI-). An analysis of propulsion at two constant speeds (0.9 and 1.8 m/s) at baseline revealed that the MRI+ group produced more work ($p=0.011$; $p=0.010$) and power ($p=0.014$; $p=0.048$) per stroke. The findings suggest that individuals who propel with greater propulsion moments have a greater risk of developing shoulder abnormalities over time.

## BACKGROUND

Many individuals who use manual wheelchairs have shoulder pain and/or signs of impingement. Daylan *et al.* reported a 71% incidence of shoulder pain among individuals with spinal cord injury (SCI)[1]. Bayley *et al.* found 24% of veterans with SCI had signs of shoulder impingement upon physical examination.[2] The onset of shoulder pain and injury can consequently lead to increased healthcare costs, loss of independence, and a reduced quality of life.

The exact cause of shoulder pain and pathology among wheelchair users is not known but is likely related to repetitive and unnatural use of the upper arms.[3] Propelling a wheelchair involves large, repetitive forces in combination with extraneous joint ranges of motion and may be a strenuous activity particularly for those who are not physically fit, have poor upper body flexibility and muscle strength, or have not received a proper wheelchair assessment, fit, or training. Longitudinal studies may provide insight into the association between shoulder pathology and push mechanics. Dicianno *et al.* performed shoulder magnetic resonance imaging studies and a biomechanical analysis on 14 wheelchair users at baseline and a two-year follow-up.[4] They found that subjects who used greater propulsion forces (resultant pushrim force > 5% of their body weight) were more likely to have an increase in shoulder MRI abnormalities over time. The objective of this study was to determine if propulsion work and power were different for subjects who presented with increased MRI evidence of shoulder pathology after two years.

## METHODS

*Subjects:* Eight men and six women with a SCI between the levels of T3 and L5 provided informed consent prior to participation. Their average age and years post injury at the start of the study were 32.8 ± 8.8 and 10.4 ± 6.7, respectively.

*Magnetic Resonance Imaging Studies:* A standardized MRI examination designed for detection of rotator cuff abnormalities was conducted on both shoulders, both at baseline and at a two-year follow-up visit. All images were read by a musculoskeletal radiologist blinded to the subject's injury level, gender, history, and biomechanical data.

*Kinetic Data Collection.* Subjects' own personal wheelchairs were fitted bilaterally with SMART$^{Wheels}$, force and torque sensing pushrims.[5] The original configuration of the subjects' wheelchairs and seating arrangements were preserved. Wheelchairs were secured to a dynamometer and a video monitor displaying the propulsion speed was placed in front of them.

After an acclimation period of five minutes, subjects were instructed to propel at two steady-state target speeds: 0.9 m/s (2mph) and 1.8 m/s (4mph) for about a minute before 20 seconds of three-dimensional force and moment data (sampling rate of 240Hz) were collected.

*MRI Variables.* Shoulder MRI findings were assessed at baseline and at the two-year follow-up using a modified grading scale of pathology based on accepted radiological criteria.[6] The studies consisted of axial FSE T2, oblique coronal FSE PD/T2, oblique sagittal FSE PD, and FSE fat suppressed T2 images. Distal clavicle edema, acromioclavicular (AC) joint degenerative disease, AC edema, acromion edema, osseous spur formation, coracoacromial (CA) ligament edema, and CA thickening were scored from 0-3, where 0 is normal, 1 is minimal, 2 is moderate, and 3 is marked. MRI pathology scores for each individual, on both left and right sides, were totaled to produce a single summary variable for each visit. The differences between total scores at the two visits were then calculated. A positive value indicated a greater number of abnormalities.

*Kinetic Variables.* The moment generated about the hub, $M_z$, the stroke length in radians, L, and the angular velocity of the rear wheels, $\theta$, were used to calculate the amount of work and power required for forward propulsion. Since the propulsive moment varied over the distance traveled and time, work and power were defined as:

$$\text{Work (W)} = \int_{x=0}^{x=L} M_z(x)dx \qquad \text{Power} = \int_{t=t_0}^{t=T} M_z(t)\theta(t)dt$$

Total work, peak and average power were determined for the first five strokes (push phase only) and then averaged across strokes. Because of high correlation, the left and right sides were combined. Work and power variables were normalized by dividing by the subject's mass in kilograms. The kinetic data obtained from the baseline measure was used in the analysis.

*Statistical Analysis.* The subjects were divided into two groups based on differences in total MRI scores at baseline and at two-year follow-up. The MRI+ group consisted of subjects whose change in MRI score was greater than one point. The MRI- group consisted of all other subjects. Chi-square analysis was used to compare the groups with respect to gender and MRI score. An independent samples t test was used to determine if differences existed between MRI+ and MRI- groups with respect to age, body mass index, years from SCI, propulsion data. For data where a t-test was not appropriate (non-normality), a Mann-Whitney test was applied. The significance level for all tests was set at 0.05.

## RESULTS

Seven subjects showed an increase in MRI abnormalities (MRI+) (mean +8.14 points; range +5 to +16) and seven subjects showed little change or improvement (MRI-) (mean –1.00 point, range –5 to +1). The groups were significantly different by the chi-square analysis ($p=0.002$). There was no significant difference in age, body mass index, or years from SCI. There were significantly more women in the MRI+ group (MRI+: 6 women, MRI-: 0 women);$p=0.001$. The MRI+ group performed significantly more work per stroke with a greater maximum power output at both target speeds in comparison to the MRI- group (Tables 1 and 2). Push length, push time, and actual speed were the same for both groups at both speeds however, subjects in the MRI- group tended to push slightly faster than the MRI+ group during the 1.8 m/s speed trial ($p=0.074$).

## DISCUSSION

Half of the wheelchair users tested exhibited significantly greater advancement in shoulder pathology after two-years. At baseline testing, these subjects performed more work and power to go the same distance and speed than subjects who had no change in shoulder pathology or showed slight improvement. This was true even though subjects in the MRI+ group propelled at slightly

Table 1: Results for target speed 0.9 m/s (2mph)

| | **Total Work (J/kg)** | **Push Length (radians)** | **Max Power (W/kg)** | **Ave Power (W/kg)** | **Push Time (seconds)** | **Actual speed (m/sec)** |
|---|---|---|---|---|---|---|
| **MRI+** | 0.10 (0.04) | 1.71 (0.24) | 0.37 (0.17) | 0.20 (0.08) | 0.52 (0.09) | 1.08 (0.05) |
| **MRI-** | 0.16 (0.03) | 1.80 (0.24) | 0.58 (0.10) | 0.30 (0.06) | 0.53 (0.10) | 1.16 (0.15) |
| **p-value** | 0.011 | 0.494 | 0.014 | 0.016 | 0.845 | 0.222 |

Table 2: Results for target speed 1.8 m/s (4mph)

| | **Total Work (J/kg)** | **Push Length (radians)** | **Max Power (W/kg)** | **Ave Power (W/kg)** | **Push Time (seconds)** | **Actual speed (m/sec)** |
|---|---|---|---|---|---|---|
| **MRI+** | 0.11 (0.06) | 1.94 (0.31) | 0.85 (0.52) | 0.36 (0.20) | 0.32 (0.04) | 2.04 (0.27) |
| **MRI-** | 0.19 (0.03) | 1.90 (0.22) | 1.20 (0.20) | 0.52 (0.06) | 0.36 (0.04) | 1.82 (0.14) |
| **p-value** | 0.010 | 0.770 | 0.048 | 0.064 | 0.102 | 0.074 |

slower speeds than the MRI- group during the 1.8 m/s trial. It seems that the MRI+ group may be facing a greater rolling resistance and in order to overcome this must generate higher propulsion moments (Mz). Several factors, including low tire pressure, weight distribution over the rear axles, slope and terrain can influence rolling resistance. A previous analysis also showed that the MRI+ group propelled with greater overall forces.[4] Not only were their tangential forces (Mz/radius of the wheel) higher, but their normal pushrim forces were higher as well. This force component does not contribute to forward propulsion but is necessary to maintain friction with the pushrim. Any non-tangential pushrim force adds to the rolling resistance and it may be that greater tangential forces are needed to propel the wheelchair at the target speeds.

Women were more likely to belong to the MRI+ group than men. Because the two groups did not differ significantly by age, body mass index, or years post SCI, other factors must explain this difference. For some reason, women performed more work per stroke and at a greater rate than men. The reason why women push differently than men is unclear, but it may provide insight into the risk factors leading to shoulder injury. It is important that women are specific targets for interventions that enhance propulsion technique and reduce pushrim forces and moments.

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# MUSCLE IMBALANCE WITH MANUAL WHEELCHAIR USE IN INDIVIDUALS WITH MULTIPLE SCLEROSIS

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## ABSTRACT

As Multiple Sclerosis (MS) advances, a manual wheelchair may become necessary. Use of a manual wheelchair may cause a muscle imbalance and possibly upper extremity injury in individuals that exhibit weakness or spasticity. The purpose of this study was to evaluate upper extremity strength of individuals with MS who utilize a manual wheelchair. An assessment of upper extremity strength was completed on nine individuals with MS and nine unimpaired controls. Both elbow and shoulder (flexion/extension) and shoulder (abduction/adduction) tests were completed at 60 deg/sec for five repetitions. The weight-normalized mean peak torque and ratio (agonist/antagonist) values were computed and analyzed. The MS group displayed a significantly ($p<0.05$) lower weight-normalized mean peak torque ratio in elbow flexion/extension compared to the controls (0.405, 0.558). Upper extremity muscle imbalances may cause shoulder problems in people with MS with extended manual wheelchair use and transfers.

## INTRODUCTION

Previous research has estimated that 250,000 people in the United States have Multiple Sclerosis (MS) (3). As MS progresses, mobility may become a problem due to lower body impairment. Wheelchair use may become a necessity for independence and often the choice is between manual and power. However, with manual wheelchair use, problems may arise with upper extremity muscle tone, muscle imbalance and possibly injury.

Research investigating the high prevalence of upper extremity injuries in people with a spinal cord injury using manual wheelchairs has been done in the past (1, 2, 4). Investigators have started to explore the premise that muscle imbalance may be a contributor to upper extremity injuries (2). In 1991, Burnham et al. investigated 39 subject's (19 male wheelchair athletes and 20 athletic unimpaired controls) upper extremity strength. They discovered that the wheelchair athletes displayed a larger abduction/adduction strength ratio when compared to the controls. The wheelchair athletes displayed weakness in the shoulder adductor muscles (latissimus dorsi, teres major, and sternal head of the pectoralis major), creating a potential risk of shoulder impingement, due to the stronger abductors (supraspinatus and anterior deltoid) pulling the humeral head further cephaled into the subacromial space. Unfortunately, upper extremity injuries that may be due to muscle imbalances have not been widely investigated in manual wheelchair users and individuals with MS. Therefore, this study may provide invaluable information concerning upper extremity muscle imbalance in individuals with MS that utilize a manual wheelchair for mobility.

## METHODS

*Subjects.* Nine (3 male and 6 female) individuals with Multiple Sclerosis (MS) that utilize manual wheelchairs as their primary means of transportation and nine (5 male and 4 female) unimpaired individuals served as a control group (CG) that were free of shoulder problems volunteered for the study. The mean age, weight and height of the MS and CG were 49.89 ± 5.11 and 37.56 ± 9.75 years, 752.02 ± 137.13 and 744.67 ± 173.55 N, 169.62 ± 9.42 and 174.70 ± 9.57 cm. Written informed consent was obtained prior to data collection.

*Experimental protocol*. After ensuring that blood pressure and resting heart rate were not elevated, subjects transferred onto a standard upright BioDex testing chair. Each subject was then secured to the chair by a lap belt and two shoulder straps that crossed the chest. The chair was then raised to a point where the legs were allowed to hang freely so that no advantage would be available. Isokinetic testing of both upper elbows (flexion/extension) and shoulders (flexion/extension and abduction/adduction) were done with a BioDex System 3 isokinetic device (BioDex Medical, Inc. Shirley, NY USA). A torque arm speed of 60 deg/sec (concentric/concentric) was used and five repetitions were performed for each test. Before the tests were performed, the subjects were familiarized with the movements.

*Statistical analysis*. Elbow and shoulder flexion/extension and shoulder abduction/adduction torque peak values for each movement over the five repetitions were averaged. A one-way ANOVA controlling for age was used to find if significant weight-normalized mean peak torque differences existed between the groups. Ratios were then calculated (agonist/antagonist) from each test. Significant weight-normalized mean peak torque ratio differences between the groups were investigated using an independent samples t-test with an alpha level set at ($p<0.05$). All statistical calculations were performed by SPSS v10.1 statistical package (SPSS, Inc., Chicago, IL).

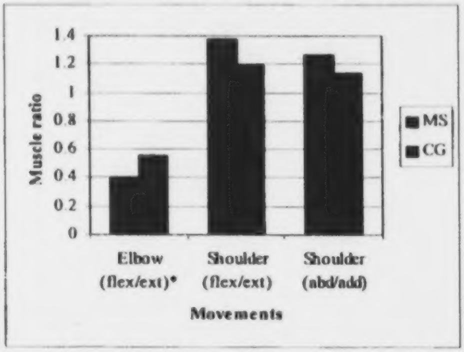
## RESULTS

The mean peak values for the right and the left sides were highly correlated ($r^2 > 0.87$ average, range 0.75 to 0.94) with $p<0.01$. Therefore, the mean of the right and left sides were combined. Table 1 presents the weight-normalized elbow and shoulder average peak torque values. Although not significant, the individuals with MS produced lower weight-normalized mean peak torque values in all of the movements. While investigating the weight-normalized mean peak torque ratios (agonist/antagonist), the individuals with MS displayed a significantly ($p<0.05$) smaller elbow flexion/extension muscle torque ratio (0.405) compared to the CG (0.558) (figure 1).

Table 1. Average weight normalized peak toque (meters) of the elbows and shoulders in both groups.

| Movements | MS Group | Control Group |
|---|---|---|
| Elbow flexion | 0.016±0.011 | 0.036±0.020 |
| Elbow extension | 0.036±0.017 | 0.060±0.024 |
| Shoulder flexion | 0.037±0.016 | 0.068±0.025 |
| Shoulder extension | 0.029±0.017 | 0.060±0.027 |
| Shoulder abduction | 0.034±0.018 | 0.057±0.023 |
| Shoulder adduction | 0.028±0.015 | 0.055±0.029 |

Figure 1. Average weight normalized peak toque ratios (agonist/antagonist) of the elbows and shoulders in both groups. * = ($p<0.05$).



## DISCUSSION

Manual wheelchair use may create secondary conditions for individuals with Multiple Sclerosis (MS). Muscle imbalance may be the consequence of manual wheelchair use, due to the strengthening of selective muscles involved with propulsion. The individuals with MS displayed lower weight-normalized peak torque values for elbow and shoulder movements (flexion, extension, abduction and adduction) compared to the control group (CG). This weakness may be due to the disease itself and or the fact that the individuals with MS were significantly ($p<0.05$) older. When further investigating the muscle ratios, the individuals with MS produced significantly ($p<0.05$) lower results in elbow flexion/extension compared to the CG. The lower elbow flexion/extension ratio seen with the MS group suggests that wheelchair use, transfers and or pressure relief has created a conditioning effect strengthening the triceps brachii. Even though the flexion/extension ratio was statistically significant, a post hoc power analysis exhibited a power of 51%. The low power obtained may be due to the small subject groups used in the analysis or the fact that there was a different male to female ratio in each group. Ivy et al. were faced with similar problems when comparing female and male subject's shoulder strength. They found that after weight normalizing (lean body mass) the data, the subject's differences were reduced.

Muscle tone may be amplified in people with MS during wheelchair propulsion diminishing motor control. Daily activities may become more difficult to perform as manual wheelchair use increases. Concerns regarding strength testing people with MS have emerged. The individuals with MS may experience increased tone in the muscle prior to testing, thus isokinetic testing may create biased results.

## CONCLUSION

To offset potential muscle imbalance problems caused by manual wheelchair use, strengthening exercises of antagonist muscles may need to be incorporated into the daily lives of people with MS. However, clinicians should be aware that strengthening exercises might exacerbate the tone, thus creating additional problems. As MS advances, problems with fatigue may escalate making manual wheelchair use more difficult or impossible to perform. At this point in time, an introduction to power wheelchair use may be warranted to insure the quality of life is maintained. While the independence of a manual wheelchair user is important, it may come at a price for some.

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# A FATIGUE ANALYSIS DURING WHEELCHAIR PROPULSION IN PATIENTS WITH MULTIPLE SCLEROSIS

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## ABSTRACT

The purpose of this study was to characterize wheelchair propulsion during a fatigue protocol in individuals with multiple sclerosis (MS) and to relate it to current clinical evaluation techniques. We found that subjects with MS who were manual wheelchair users (n = 13) had near normal strength, sensation, and tone on physical examination. Despite this finding, individuals with MS propelled their wheelchair slower and were unable to maintain this slow speed for a five-minute period when compared to a control group. Continued research should focus on the development of more effective clinical evaluation methods for determining if individuals with MS are appropriate for manual wheelchairs.

## INTRODUCTION

With the changing policies for reimbursement of assistive technologies, insurance companies are requiring substantial scientific evidence to support prescription. Wheelchair prescription is particularly critical considering it is, for many, the primary or only means of mobility, and often involves use for several hours each day. In a study by Perks et al, 59% of individuals with MS in the United Kingdom said they felt their wheelchair did not meet their mobility needs[1]. This suggests that there is a divide between the needs of the wheelchair user with MS and the assistive technology provided. Individuals with MS present unique challenges secondary to fluctuating symptoms and functional capacity based upon disease activity. Primary limiting factors to functional abilities in this population include weakness and fatigue. Because of the variability in disease presentation, little research to date exists relating mobility and fatigue. Therefore, the purpose of this study was to characterize the ability to propel a wheelchair during a fatigue protocol in individuals with MS and to determine if current clinical evaluation techniques for wheelchair prescription can detect limitations. To characterize propulsion, we looked at velocity and cadence. Normal walking speed is just over 1 m/s this can be considered a a functional standard for wheelchair propulsion.

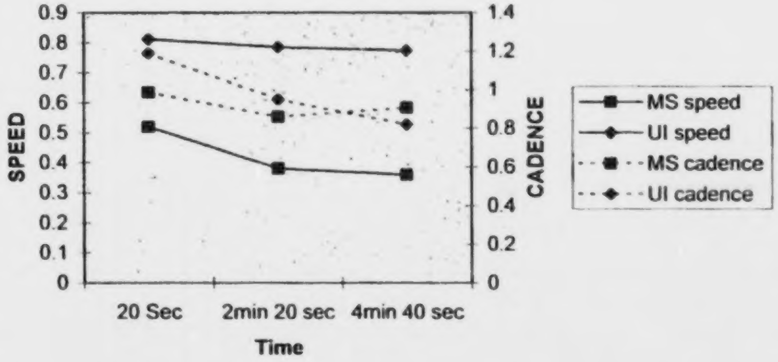
## MATERIALS AND METHODS

Subjects: 13 patients with multiple sclerosis (MS) and 15 unimpaired individuals (UI) were tested. The average age of the group with MS and the ND group was 49.3 and 39.1 years, respectively. Inclusion criteria for the group with MS included diagnosis of MS made by a medical doctor, the use of a manual wheelchair, the absence of upper extremity injury, and the absence of a cardiac condition that could limit the individual's ability to propel a wheelchair during testing. All subjects gave written informed consent. Physical Exam: A physical or occupational therapist performed the physical examination on all subjects with MS. Three measures were considered for the physical exam: motor strength, light touch sensation, and spasticity. Motor strength and light touch sensory perception was evaluated using the American Spinal Injury Association examination[2]. Spasticity was quantified using the modified Ashworth scale (0-4) [3]. Kinetic Testing: The manual wheelchairs of the subjects from the MS group were used for their kinetic testing. The laboratory provided a manual wheelchair for those participants in the UI group. Wheelchairs were secured onto a two-drum dynamometer via a four-point securement system. Bilateral SMART$^{Wheels}$, capable of measuring three-dimensional forces and moments about the pushrim were used in this study[4]. Subjects were asked to propel their wheelchair at a self-selected speed for a five-minutes. Data were collected during the initial twenty seconds of propulsion, 2 minutes and 20 seconds into the testing, and during the final twenty seconds of the trial. In a second trial, subjects were asked to propel their wheelchair for 20 seconds, with a target speed of 1m/sec. For each time trial, speed and cadence were calculated using the average of the first five strokes. Data were collected at a sampling rate of 60Hz. Group differences over time were determined using a repeated measure ANOVA with a level of significance at $p< 05$.

## RESULTS

Results of our physical examination revealed that almost all of the subjects with MS had near normal sensation and strength, with exception of one of the subjects, who had a 3/5 muscle grade for bilateral C8 myotomes. Only one subject with multiple sclerosis was found to have notable elbow flexion and extension spasticity (2/4 Modified Ashworth scale). When asked to propel at a self-selected speed, the MS group propelled significantly slower than controls. In addition, speed significantly decreased throughout the trial in the MS subject group, whereas the UI group was able to maintain a constant speed throughout. Propulsional cadence (strokes/sec) remained relatively constant throughout the trial.

**Figure 1. Comparison of speed and cadence in MS vs. UI**



During the 1m/sec speed trial, UI subjects propelled the wheelchair with an average speed of .88m/sec. Subjects with MS, however, propelled their wheelchairs significantly slower ($p= .024$), with an average speed of .69m/sec.

## DISCUSSION

Aronson (1997) has made an association between mobility and quality of life[5]. With a decline in mobility often comes a decline in sociability, self-satisfaction, and motivation. For individuals with multiple sclerosis, 50% require some type of mobility assistance[6]. With this in mind, our laboratory has sought to determine why it is that such a large percentage of individuals with MS feel their current wheelchair does not meet their mobility needs[1]. Our results show that, during a fatigue trial, although our case subjects propelled the wheelchair with a cadence similar to that of controls, their speed was 36-54% slower than control speeds. The effects of fatigue in our case subjects were evident just a couple of minutes into the trial. Functionally, these subjects would not be able to keep up with peers. Taking into account that our fatigue trial was performed at a self-selected speed, we conducted a second trial to determine whether the individuals with MS were physically able to propel the wheelchair at our functional standard, 1m/sec. Again, these subjects were unable to attain this target speed, propelling their wheelchair significantly slower than controls. This was true despite the fact that a physical examination showed almost no impairment. This same examination is commonly used as a standard to determine who qualifies for a power wheelchair. This raises the question as to how often a manual wheelchair is erroneously prescribed to individuals with MS for whom it is, in fact, not a functional means of mobility. Future research should seek to develop more effective clinical testing protocols that accurately predict successful propulsion and endurance in individuals with MS.

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# PHYSIOLOGICAL COMPARISON OF A PUSHRIM ACTIVATED POWER ASSIST WHEELCHAIR AND TRADITIONAL MANUAL WHEELCHAIR PROPULSION AMONG PERSONS WITH TETRAPLEGIA

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## ABSTRACT

The purpose of this study is to compare the amount of energy expended by users when pushing their own manual wheelchairs and a pushrim activated power assist wheelchair (PAPAW). For persons with disabilities who have upper extremity weakness, the traditional manual wheelchair is an effective, but at times can be an inefficient means of mobility (1). Fifteen subjects with tetraplegia will be asked to propel their own manual wheelchair and a PAPAW on a wheelchair dynamometer (roller system) at varying resistances. Initial test results reveal that amount of energy expended by subjects between the two wheelchairs is up to 45% less for the PAPAW across the resistances.

## BACKGROUND

Wheelchairs are used as an important tool in the mobility of people with disabilities. For many years, the types of mobility devices have been available have been limited to powered wheelchairs, manual wheelchairs, or powered scooters. Pushrim Activated Power Assist Wheelchairs (PAPAWs) offer an alternative between manual wheelchairs and powered wheelchairs. The PAPAW is an electrically powered add-on unit for common manual wheelchairs. The unit automatically supplements the users manual pushrim input with additional rear-wheel torque for up to 4 miles per hours traveling velocity. The amount of added torque is provided proportional to the user input to the pushrims. Movement and braking assistance is provided in both forward and backward directions. PAPAWs tested during this study are the *JWII*, developed by the Yamaha Motor Corporation (see Figure 1).

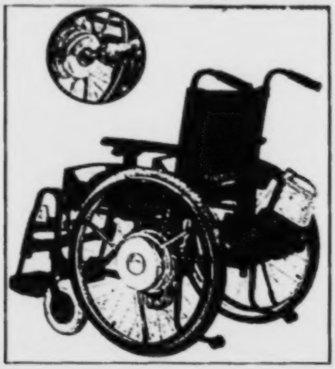
**Figure 1**

An important issue for wheelchair users is injuries related to propelling the wheelchair. The upper extremity serves as the main means of propulsion for the wheelchair user and has been described as "walking with the arms." (2) The upper extremity was not designed for this sort of function and it is not a surprise that many wheelchair users complain of shoulder, elbow and wrist pain. Previous studies have shown that wheelchair propulsion efficiency can range from about 5% to 18% (3). Alternative methods of wheelchair propulsion, such as lever-drive units, arm cranks, and geared hubs, have been developed. For the most part, these have fallen short in presenting feasible and commercially appealing solutions. Thus, the testing and development of a product that is both appealing and practical in meeting mobility needs is an important issue that should be welcomed by consumers, researchers, and clinicians.

## RESEARCH QUESTION

Are there significant differences in energy expended for persons with tetraplegia while propelling a PAPAW and their own manual wheelchair through different types of resistances on a wheelchair dynamometer?

## METHOD

Each subject was provided with information about the safety and intent of the tests, and signed consent forms were obtained prior to any testing. Additionally, subjects were asked to abstain from eating for two hours prior to testing. For data collection, subjects were asked to propel both their own manual wheelchair and a PAPAW in random order on a computer controlled wheelchair dynamometer (see Figure 2). They performed six total trials through three resistance conditions for each wheelchair configuration: 1) 2 miles per hour (MPH) with slight resistance, 2) 2 MPH with moderate resistance, and 3) 2 MPH with high resistance. Each of the six trials was three minutes in length with data collected for the final 30 seconds of the last minute. Heart rate was continuously monitored throughout testing. Upon completion of testing, the subject's heart rate was continuously monitored for fifteen minutes during cool-down.

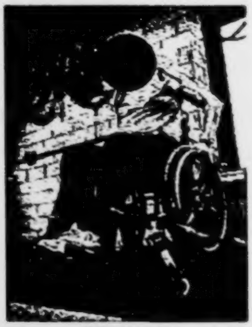
**Figure 2**

Metabolic data were acquired using a SensorMedics model 2900 metabolic Measurement Cart (The CardioPulmonary Care Co.). This system collects expired gases from the subject via mouthpiece and tube. The subject's nose is pinched with a nose-clamp to prevent air loss from the system. Subject economy (i.e., steady state rate of oxygen consumption), respiratory exchange ratio, ventilation rate, and ventilation volume is collected from the system and presented graphically. Heart rate data was collected using a Polar Vantage XL heart-rate monitor model 45900 (polar USA, Inc.). Additionally, the OPTO*TRAK* 3D 3020 motion analysis system (Northern Digital, Inc.) was used to collect the position data of infrared markers (IRED) placed on the wheelchair user's body.

## RESULTS

The physiologic variables compared between the two wheelchair configurations (PAPAW vs. Manual) were: Oxygen consumption ($VO_2$ml/kg x min, $VO_2$ml/min), Ventilation ($V_E$L/min), and heart rate (BPM). Currently two subjects have completed testing, and the means of these variables are presented in Table 1. The change in heart rates and oxygen consumptions were calculated using the following equations:

$$(1)\ \Delta VO_2 = (VO_2 exer - VO_2\ rest) / VO_2\ rest$$
$$(2)\ \Delta HR = (HRexer - HRrest) / HRrest$$

## DISCUSSION

As initial testing reveals, a PAPAW operates much like a traditional manual wheelchair but requires less effort to propel. They can be particularly useful for users with tetraplegia, because upper extremity weakness is typically found in these types of users. From previous testing and initial results, PAPAWs have the potential to reduce stress on upper extremities during wheelchair propulsion, reduce metabolic energy expenditure, improve function during daily activities, and improve mobility and participation within the user's community. (4) Further testing includes recruiting and collecting the remaining subjects and performing data analysis from these tests. Subject economy (i.e., steady state rate of oxygen consumption), respiratory exchange ration, ventilation rate, and ventilation volume will be compared using analysis of variance (ANOVA) across the three resistance conditions and between the two wheelchair configurations (with and without the PAPAW). Future studies involving the *JWII* include an activities of daily living evaluation, and home trials, where the subjects will take the *JWII* home with them for two weeks, and record time spent in the wheelchair, distances traveled, and a complete of a consumer satisfaction survey.

**Table 1: Results of Metabolic Testing with the PAPAW and Subjects' Manual Wheelchair**

| Trial | Δ VO$_2$ (mL/min) Mean | | Ventilation (L/min) Mean | | Δ VO$_2$ (mL/kg•min) Mean | | Δ Heart Rate (BPM) Mean | |
|---|---|---|---|---|---|---|---|---|
| | Personal | PAPAW | Personal | PAPAW | Personal | PAPAW | Personal | PAPAW |
| Easy | 2.00 | 2.21 | 23.1 | 18.7 | 2.04 | 2.14 | 0.44 | 0.17 |
| Moderate | 1.53 | 0.38 | 26.6 | 13.5 | 1.45 | 0.40 | 0.49 | 0.23 |
| Difficult | 2.21 | 0.79 | 28.0 | 25.6 | 2.13 | 0.79 | 0.97 | 0.69 |

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# USE OF THE INDEPENDENCE™ 3000 IBOT™ TRANSPORTER AT HOME AND IN THE COMMUNITY: A PILOT STUDY

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**ABSTRACT:** The INDEPENDENCE™ 3000 IBOT™ Transporter (IBOT) is an electronically stabilizing mobility device for people with disabilities. The purpose of this study was to gain experience with the IBOT at home and in the community using four expert wheelchair users, who used the IBOT as their primary mobility device for one week. This pilot study is based upon data recorded from a computerized data-logger and reports from each participant. The four participants were male manual wheelchair users with traumatic spinal cord injuries ranging from the T7-L1 levels. During the course of this study, the IBOT proved to be an effective mobility device and it's unique capabilities afforded new opportunities for the participants.

**BACKGROUND:** The INDEPENDENCE™ 3000 IBOT™ Transporter (IBOT) is an advanced wheeled mobility device that incorporates sensors and actuators for dynamic stabilization, speed control, self-diagnosis, and for changing operational functions. Three redundant computers help to maintain stability, increase user control, and assure safe operation. An important feature of the IBOT is that the device contains an internal modem that allows communication with a service representative at a distance. This provides the potential to down-load operation logs that the IBOT records and to up-load software changes.

Structurally the IBOT is based upon a chair mounted through linkages to a wheeled base. The IBOT's drive train includes four primary wheels, each controlled through its own set of electric motors, and two caster wheels. The two sets of drive wheels (right and left) form a cluster. Each cluster may rotate about its central axis while the wheels may rotate about their hubs. This configuration allows the IBOT to traverse non-uniform surfaces, inclines, and to climb curbs.

The IBOT can be operated in four functions: Standard; 4-wheel; Balance; and Remote. In Standard Function the IBOT operates much like a common electric powered wheelchair. When driving in "4-wheel Function" the clusters are allowed to rotate, providing the freedom to negotiate obstacles or uneven terrain. The cluster design, combined with specialized controls incorporated in the IBOT, allows the device to balance on two wheels. This mode, known as "Balance Function" raises the seat height permitting the occupant to reach for high objects or to come to eye level with a person who is standing or walking. In "Remote Function" the user can detach the control panel, fold down the backrest, and drive an unoccupied IBOT to assist in loading the device for transport or position the device for transfers.

**RESEARCH QUESTION:** The objective of this pilot study was to collect data on the use of the IBOT at home and in the community with four expert wheelchair users. This is the first study to allow wheelchair users to drive the IBOT independently in their home and community.

**METHOD:** This pilot study was conducted at two sites: Manchester, NH and Pittsburgh, PA and is based upon data recorded from a computerized data-logger and reports from each participant. Four male manual wheelchair users with traumatic spinal cord injuries ranging from the T7-L1 levels and whose mean (SD) age was 45 (2.9) years participated in this study. All subjects used manual wheelchairs as their primary means of mobility. Their mobility skills were characterized as propelling faster than walking speed and able to travel in a "wheelie" position for at least ten feet. The participants were considered "experts" because they had been involved with various aspects of the design and development of the IBOT and/or had extensive laboratory driving experience with the IBOT.

Each participant successfully completed a standardized assessment and an independent training session in order to ensure that they were knowledgeable in each of the device's functions and able to safely operate the device in the community. After successful completion of the assessment and training, the participants took the device home for one week to use as their primary mobility device. The participants were instructed that they would be called daily by a service technician to download data from the IBOT's internal data-logger.

**RESULTS**: The study participants used the IBOT to perform a variety of activities within the home, work, and community settings. Based on participant's reports, the greatest benefits with the IBOT were being able to easily drive over grass, gravel, and dirt in 4-Wheel function making areas around their homes more accessible. The participants also reported that the ability to reach higher levels and to communicate with friends and colleagues at eye-level in balance function was desirable. Table 1. provides a summary of the data-logger results. Over the course of the week, the greatest distance (32.6 km) was driven in standard function, and the most time (108 hr) was spent in standard function. The mean hours of driving per day were greater during the weekdays (7.5 hr) when compared to the weekends (5.6 hr). However, the mean kilometers driven per day were greater on the weekends (3.7 km) versus the weekdays (3.0 km). The data also shows that the various functions were accessed frequently (1494 accesses).

|  | All Functions | Standard | 4-Wheel | Balance |
|---|---|---|---|---|
| Weekdays/Weekends |  |  |  |  |
| Distance/day (km) | 3.2 ± 1.4 | 1.4 ± 0.9 | 1.2 ± 1.3 | 0.7 ± 0.8 |
| Total Distance (km) | 77.4 | 32.6 | 27.6 | 17.2 |
| Hours/day (hr) | 6.8 ± 2.4 | 4.5 ± 2.6 | 1.2 ± 1.0 | 1.1 ± 1.3 |
| Total Hours (hr) | 163.9 | 108 | 29.9 | 26 |
| Total Accesses (n) | 1494 | 737 | 536 | 221 |
| Weekdays |  |  |  |  |
| Distance/day (km) | 3.0 ± 1.3 | 1.6 ± 0.7 | 0.7 ± 0.7 | 0.7 ± 0.8 |
| Total Distance (km) | 47.9 | 25.1 | 11.6 | 11.2 |
| Hours/day (hr) | 7.5 ± 2.4 | 5.6 ± 2.4 | 0.8 ± 0.5 | 1.1 ± 1.2 |
| Total Hours (hr) | 119.5 | 89.3 | 13.4 | 16.8 |
| Accesses/day (n) | 61.4 ± 29.6 | 30.4 ± 13.1 | 22.1 ± 11.8 | 8.9 ± 6.1 |
| Weekends |  |  |  |  |
| Distance/day (km) | 3.7 ± 1.6 | 0.9 ± 1.1 | 2.0 ± 1.7 | 0.8 ± .9 |
| Total Distance (km) | 29.5 | 7.5 | 16 | 6 |
| Hours/day (hr) | 5.6 ± 1.9 | 2.3 ± 1.4 | 2.1 ± 1.4 | 1.2 ± 1.5 |
| Total Hours (hr) | 44.4 | 18.7 | 16.5 | 9.2 |
| Accesses/day (n) | 63.9 ± 33.9 | 31.4 ± 17.6 | 22.8 ± 12.6 | 9.8 ± 6.6 |

**Table 1. Summary of activity recorded from data-logger (Mean ± SD)**

**DISCUSSION:** There have been considerable advances in wheeled mobility over the past 20 years. [1] However, the IBOT is likely the most sophisticated and complex mobility device under development for people with disabilities. Devices like the IBOT have the potential to provide greater functional ability by allowing wheelchair users access to areas and activities that are currently inaccessible.

Through participants' reports, the general consensus was that the IBOT's most valuable features were the unique functions of balance and 4-wheel. The participants felt the experience of being eye-level with a person standing or walking and participating in activities at an increased height was advantageous. In addition, the IBOT afforded new opportunities in 4-wheel function. Although the participants were highly skilled manual wheelchair users capable of negotiating curbs and uneven terrain in their manual wheelchairs, the IBOT could travel several kilometers over uneven or soft terrain and allowed for exploring new areas (e.g., wooded areas) and activities (e.g., hiking).

On average the subjects drove about 3.2 km per day in the IBOT and spent about 6.8 hours per day in the IBOT. This equates to an average speed of 0.13 m/s, which indicates that much of the time was spent with starts and stops. Subjects drove further during weekends (3.7 vs. 3.0 km), and traveled further in 4-wheel function (2.1 km) than standard (0.9 km) or balance (0.8 km) on weekends. These results are similar to those reported by Cooper et al. for a group of electric powered wheelchair users and by Arva et al. for a group of manual wheelchair users. [2], [3] The distance traveled per day was evenly distributed across functions; however, the most time was spent in standard function. This is likely due to standard function being used indoors.

Further study of the IBOT is warranted. A diverse population of wheelchair users needs to be studied to determine if the experiences of the expert participants were representative of the general wheelchair user population. It is promising that a device like the IBOT is in development, and that people with disabilities may have access to expanded environs.

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# COMPARISON OF VIRTUAL ELECTRIC POWERED WHEELCHAIR DRIVING USING A POSITION SENSING JOYSTICK AND AN ISOMETRIC JOYSTICK

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## ABSTRACT

Previous studies indicate that people who exhibit intention tremor may show some improvement in performing tracking tasks using an isometric joystick [4] [5]. The objective of this study was to compare the performance of a conventional position sensing joystick (PSJ) to an isometric joystick with Compensation Algorithms (IJCA) in a virtual environment. Subjects consisted of a population with different disabilities. The results showed no significant difference between the two joysticks. Further work should include more complex tasks and greater training.

## BACKGROUND

Traditionally, position sensing joysticks (PSJ) have been used in electric power wheelchairs (EPW) as the preferred control device. However, some people with disabilities do not have the motor skills to operate a PSJ due to severe intention tremor, spasms, weakness, and limited range of motion [4]. Specialists have proposed that the use of an isometric joystick (IJ), which senses the magnitude and direction of applied force while the stick does not move, may provide a proportional control alternative [2]. Several studies [4] [5] have compared IJ performance with the performance of a conventional PSJ in populations with different disabilities. The results have demonstrated some significant differences in performance in favor of IJ [4]. Cooper et al. have proposed that the use of an Isometric Joystick with Compensation Algorithms (IJCA) could enhance the control over the EPW by means of signal conditioning algorithms that aim to lower the detecting threshold for the onset of motion. To date, no study has compared the performance of an IJCA with a PSJ. Furthermore, virtual assessment and training environments have been investigated to evaluate someone's ability of using the IJ (fig.1). They provide an inexpensive useful basis for optimizing an IJ. This can eliminate some of the time consuming and safety concerns with training [1]. Therefore, the aim of this study was to extend our previous work on the development and testing of an IJCA in virtual environment in order to improve driving performance of EPW users, and possibly provide a means of allowing people who are unable to independently drive an EPW to do so.

## RESEARCH QUESTIONS

The overall aim of this study was to compare the performance of the PSJ and the IJCA in EPW users in a virtual world (subject using a computer to emulate wheelchair) in six different tasks: following line in vertical, horizontal, circle clockwise, circle counter clockwise, square clockwise and square counter clockwise. The specific aims were:

**Specific Aim 1:** Compare the root mean square error (RMSE) of the PSJ against the IJCA in EPW users in six different conditions. It is hypothesized that the RMSE of the IJCA for all 6 conditions will be smaller that the RMSE of PSJ in EPW users.

**Specific Aim 2:** Compare the time of the PSJ against the FSJ in power wheelchair users in six different conditions. It is hypothesized that the time of IJCA for all six conditions will be smaller than the time of PSJ in EPW users.

## METHODS

The EPW used in this study was a Quickie P300 (Sunrise Medical, Ltd.). A standard armrest mounted PSJ and an IJCA were used in this study. The PSJ was a commercially available device commonly (Flight Link Controls, Inc.) used on electric powered wheelchairs. The IJCA was designed and fabricated in our laboratories (fig.2). During the virtual driving tasks, the subjects drove the test wheelchair on a wheelchair dynamometer with a 20" computer monitor positioned within each subject's field of vision. Ten experienced EPW users (9 males) participated in this study. Subjects have used EPW for an average of 9.8 ± 5.7 years. Seven subjects had cervical spinal cord injuries, two had multiple sclerosis, and one had experienced a cerebral vascular accident. The mean age was 47 ± 9.8 years. Subjects were recruited via fliers distributed to clinics and community organizations.

The two joysticks, PSJ and IJCA, were presented randomly. Subjects were asked to complete six virtual driving tasks following the track accurately and to drive as quickly as possible. The first task was to move the sprite along a seven-meter long vertical line displayed on the monitor. The second task was to move the sprite along seven-meter long horizontal line from left to right. The next task was to track the sprite around a square with six meters to a side in the clockwise direction, followed by the counter clockwise direction. The final task was to move the sprite clockwise around a circle with an effective diameter of six meter then to trace the circle with the sprite in the counter clockwise direction. The testing order for the tasks was selected for increasing the challenge. The virtual driving tasks were presented in a "birds eye view" and were displayed to use the entire screen. Subjects were asked to complete each virtual task five times. The first three of the five virtual driving trials that were within the two wheelchairs width were included in the analysis. The lateral deviation of the sprite from the course at each instant was used to determine the tracking error during virtual driving and was named the root mean square error (RMSE). The time to complete each of the driving tasks was also analyzed and recorded in seconds.

Statistical analysis was completed using SPSS software. Means and standard deviations of RMSE and Time were computed for individual and combined tasks for each joystick. Differences in RMSE and Time between the two joysticks were determined for each task and for the averaged 6 tasks using paired t-tests. The alpha level was set at 0.05.

## RESULTS

Descriptive statistics and the significance level of each paired t-test of RMSE and Time for PSJ and IJCA can be seen in Table 1. Data is presented as means and standard deviations of RMSE and performance Time of each task using the PSJ and IJCA. The analysis has shown no significant difference between performance using the PSJ and the IJCA (p> 0.05).

Table 1: Performance results of PSJ and IJ.

| **Task** | **Joystick** | **RMSE** | | | **Time** | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Signif | Mean | SD | Signif |
| **Up/Down** | **PSJ** | 15.29 | 14.81 | .678 | 26.76 | 27.75 | .911 |
| | **IJCA** | 15.84 | 15.11 | | 27.27 | 20.69 | |
| **Left/Right** | **PSJ** | 17.91 | 9.13 | .639 | 20.54 | 6.81 | .057 |
| | **IJCA** | 19.85 | 9.71 | | 29.76 | 16.27 | |
| **Circle Clockwise** | **PSJ** | 18.73 | 8.32 | .139 | 55.83 | 19.41 | .242 |
| | **IJCA** | 26.48 | 17.94 | | 68.09 | 31.79 | |
| **Circle Counter Clockwise** | **PSJ** | 17.38 | 11.53 | .179 | 43.42 | 13.49 | .121 |
| | **IJCA** | 20.84 | 11.39 | | 63.47 | 31.24 | |
| **Square Clockwise** | **PSJ** | 27.30 | 11.90 | .624 | 84.80 | 43.87 | .413 |
| | **IJCA** | 29.33 | 16.94 | | 101.02 | 66.56 | |
| **Square Counter Clockwise** | **PSJ** | 31.97 | 17.07 | .436 | 72.17 | 33.54 | .062 |
| | **IJCA** | 29.79 | 12.51 | | 101.82 | 68.95 | |
| **All activities** | **PSJ** | 21.73 | 9.61 | .118 | 284.39 | 87.57 | .175 |
| | **IJCA** | 24.72 | 13.78 | | 363.47 | 219.49 | |

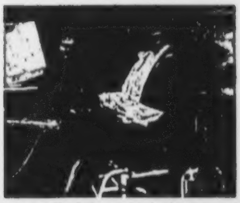

Figure 1. Subject driving an EPW through a virtual environment.

Figure 2. Isometric Joystick

## DISCUSSION

We found no significant differences between the two joysticks for any of the variables recorded. Cooper et al found significant results in a study that compared PSJ with IJ [4]. IJ was better than the PSJ while driving forward, while turning and while driving backward [4]. Hence, these results could lead us to think about few possibilities that could have made some difference in favor of the IJCA. The first explanation is that all subjects have not had experience using the IJCA. Most people exhibit a temporary reduction in performance when introduced a new technology [4]. The second possibility was that experimental tasks were too simple for people who already drive EPW with a joystick. Increased complexity of the task may help to accentuate the differences in the interface devices [4]. Another possibility is that subjects had good motor hand control, so a difference in performance between two joysticks may not be seen. For future studies, subject with IJCA could be trained more thoroughly before starting the investigation or we can start the investigation with individuals that are able to operate the PSJ but do not have any previous experience. We could take individuals that were just discharged from a rehabilitation hospital. More difficult tasks need to be considered and selected to be more similar to common activities of daily living such as human traffic, cross traffic, ramps etc. [4]. Information from individuals more severely impaired, such as distonic, athetoid and/or ataxia cerebral palsy, would be useful to know the relevant performance benefit of IJCA.

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## ACKNOWLEDGEMENTS

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# REVIEW OF ALTERNATIVE POWER SOURCES FOR POWERED WHEELCHAIRS

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## ABSTRACT

Current power systems used in powered wheelchairs have proven to be reliable and usable, however, there are many reasons why alternative power systems should be considered. For example, the lead acid battery/electric motor system is heavy, which limits the ability to produce powered wheelchair technologies benefiting from lighter weight.

Research in power systems being considered for transportation systems and stationary power generation has resulted in new power generation systems or improvements in more familiar power generation systems that may have unique benefits for powered wheelchairs. This paper reviews several of these technologies, including fuel cells, hybrid electric power systems, and advanced internal combustion engine systems for possible use in powered wheelchairs.

## BACKGROUND

Powered wheelchairs have had a remarkably positive effect on the lives of those needing mobility assistance. At the present time, more than 150,000 Americans are being assisted by these devices. Continuous design improvements during the approximately 45 year history of powered wheelchairs have resulted in rapid increase in the rate at which people are choosing to use this form of mobility assistance.

Research in transportation and stationary power generation sectors has focused on advanced power generation systems such as fuel cells and hybrid electric power systems. As a result of this effort, there are significant improvements which mean that there are configurations of the advanced power generation systems representing intriguing alternatives to the conventional battery/electric motor system. These alternatives may allow for significant enhancement in the capabilities of the powered wheelchair, for example in wheelchair weight and range.

## NEED FOR ALTERNATIVE POWER SYSTEMS

Commercially available powered wheelchairs are powered by a combination of lead acid batteries and electric motors. Consideration of alternatives to this power system is desirable for several reasons: First, the lead acid battery/electric motor system is heavy, in fact, on the same order as the user of the chair. Thus, the weight of this power system has a dominant effect on the chair design. There may be good reasons to have a heavy power chair, stability being a common trait associated with mass, however, there are many problems caused by such heavy chairs, for example in transportation. In addition, all other aspects of the dynamic performance of the chair are dominated by the weight of the system.

Second, the range of the powered wheelchair using batteries is finite between charges. In addition, it is often unclear to the user if sufficient battery power remains to attempt longer trips, thus limiting independence. To recharge the chair the user must have access to AC power and a charger, again limiting independence. Because charging a battery takes time, even when AC power is available, the user has to wait for the battery to recharge.

Finally, the limited energy of lead acid batteries limits the use of the wheelchair power pack to just powering the wheelchair. If, for example, additional power was needed for such things as a personal environmental control system or an assistive robot arm, then alternative methods of power would be necessary. If alternative wheelchair technologies, including gyro-stabilized systems like those found in the IBOT 3000™ become a reality, again additional or perhaps redundant power systems will be required for the chair to have acceptable usability and safety.

**Alternative Power Systems**

1) Fuel Cells/Electric Motor Systems

A fuel cell is a device in which there is a direct conversion of fuel and oxygen to electrical energy [1,2]. Fuel cells are the subject of much current research work because of the possibility of very high conversion efficiencies of fuel to electrical energy, and the possibility of zero harmful emissions from the conversion process.

Fuel cells have been developed in a wide variety of different configurations depending on the type of fuel source available, and the method of conversion of fuel to energy. These different configurations are shown in Table 1. As illustrated in Table 1, there are fuel cell technologies that would not be candidates for use in powered wheelchairs, for example, because of high operating temperatures limiting the transient performance. There are also other questions for fuel cells that will have to be answered for the power wheelchair use. For example, if hydrogen is needed as the fuel, how is the hydrogen obtained and stored? This will have to be answered before these fuel cells would be considered real alternatives for powered wheelchairs.

2) Hybrid Electric Power Systems

"Hybrid Electric Vehicles (HEV) combine two or more energy conversion technologies (e.g., heat engines, fuel cells, generators, or motors) with one or more energy storage technologies (e.g., fuel, batteries, ultracapacitors, or flywheels.)" [3] For the application typically thought of for HEVs, i.e. automotive, bus, and light truck transportation, the goal is to produce a system that will have higher efficiencies and reduced harmful emissions when compared with an ordinary internal combustion engine. Application of a hybrid electric system to powered wheelchairs would be done primarily for a different reason. Specifically, the addition of energy in the fuel, instead of just batteries, would greatly expand the available energy and power.

Hybrid electric power systems are available in two configurations. In the series configuration, the components of the system are aligned in series, so that the path of power is sequential. For example, in a typical application of a series system, an internal combustion engine would be directly coupled to an alternator to produce electrical power. This power can be used to drive an electric motor driving the wheels. This power can also be used to charge on board batteries. Because the engine is decoupled from the non-steady driving demands, it can operate at a narrow speed and load range, which can result in greatly improved efficiency and reduced emissions.

In contrast, the parallel configuration allows for power to flow along parallel paths. In this case, the internal combustion engine can be used to produce electrical power or it can be used to produce actual motive power at the wheels.

Two other variations of hybrid systems, whether parallel or series configuration, are important candidates for the powered wheelchair application: These are the battery/electric motor/internal combustion engine hybrid system and the fuel cell/electric motor/internal combustion engine hybrid system. The difference between the two is whether a battery is used to store electrical energy for use when needed, or a fuel cell is used to produce electrical energy when needed. In the latter case, the energy is stored in the fuel prior to use. There are many differences in the design of these two systems, for example in the relative sizes of the other components. These differences will need to be accounted for to ensure that the most promising systems are investigated.

Table 1: Fuel cell type and characteristics and applicability to powered wheelchairs.

| **Fuel Cell Type** | **Conversion Efficiency** | **Operating Temperature** | **Fuel** | **Powered Wheelchair Application?** |
|---|---|---|---|---|
| Phosphoric Acid | >40% | 400 °F | Hydrogen | No |
| Proton Exchange Membrane (PEM) | >40% | 200 °F | Hydrogen | Yes |
| Molten Carbonate | NA | 1200 °F | Hydrogen, CO, Other common hydrocarbons | No |
| Solid Oxide | 60 % | 1,800 °F | Hydrogen, CO | Maybe |
| Alkaline | 70 % | 70 ° | Hydrogen | Yes, filter CO2 |
| Direct Methanol Fuel Cells (DMFC) | 40 % | 120-190 °F | Methanol | Yes, fuel handling an issue |
| With Reformers | | 650-700 °C | Gasoline, Natural Gas, Methanol | CO poisoning, mass, volume, cost |

3) Internal Combustion Engine Systems

In addition to the technologies already described, there has been consistent improvement in internal combustion engine technologies potentially suitable for powered wheelchair use. For example, American Honda Motor Company is currently manufacturing very small four-stroke engines, designed to replace the two-stroke engines currently being used in devices such as string trimmers and leaf blowers.[4] The new four-stroke engines have nearly the same power density as the two-stroke engines (here power density is defined as power output per unit weight) however, with greatly improved fuel economy and significantly reduced exhaust emissions. To give an example of the interesting technology being used in these engines, the model producing one horsepower, which would be ample for powered wheelchairs, weighs 7.3 lbs. and is less than 10 in. on a side.

In additional to the mechanical design improvements, there have been significant improvements possible for the combustion system. For example, it is possible to operate these engines with LPG fuel using an advanced fuel metering system combined with a three-way catalyst for exhaust emissions control. Doing so produces an engine that is extraordinarily quiet, fuel efficient, and with clean exhaust i.e. vanishing low levels of hydrocarbon and CO emissions. In addition the engines are reliable and cost effective. For example, the Honda engine system would be priced somewhere in the $20-$30 range to an OEM. The addition of the advanced fuel metering and catalyst system would add an additional $30-$50 to the total cost to the OEM. Engines configured this way are being used to power floor buffers used in grocery stores and other public buildings, meeting government regulations for indoor air quality. [5]

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# DESIGN OF A FORWARD FOLDING ULTRALIGHT WHEELCHAIR

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## ABSTRACT

Boarding aircraft can be a time consuming and even a frustrating task for both wheelchair users and airlines. A wheelchair that is able to fold into an overhead compartment or suit closet of aircraft would allow wheelchair users to board with their own wheelchair and stow the wheelchair. This wheelchair could also allow for easier transfers in and out of automobiles. This project aims to develop a forward folding ultralight wheelchair (FFUWC) that is able to fit in an overhead compartment or suit closet of aircraft. The goal is for the performance and feel of the FFUWC to be comparable to an adjustable ultralight wheelchair. Two prototypes have been built: a nonadjustable and an adjustable prototype. The nonadjustable prototype has been in use for a year without any major failures. The adjustable prototype was tested using the ANSI/RESNA standards for wheelchairs and changes will be made to the wheelchair due to permanent deformation of a member of the frame.

## BACKGROUND

About 2.2 million Americans aged 15 and over were wheelchair users in a 1997 U.S. Census Bureau study [6]. According to the U.S. Department of Transportation, between 1998 and 1999 complaints about airlines by people with disabilities have doubled [7]. Accessibility on airplanes has always been a problem for wheelchair users due to the limited space on airplanes. The problems have caught the attention of Congress and in 1986 the Air Carrier Access Act was passed. It simply states that, "No air carrier shall discriminate against any otherwise qualified handicapped individual, by reason of such handicap, in the provision of air transportation [5]." Still, this law does not cover all problems of wheelchair users. Airlines are not required to allow someone to use their own wheelchair when boarding an airplane. When boarding the aircraft, they may have to transfer into a specialized wheelchair narrow enough to assist in transporting someone to their seat. This transferring method causes unnecessary steps to get people into their seats and may cause uncomfortable moments for some. It also causes airlines to have the resources necessary to assist people with transferring needs.

Another problem that manual wheelchair users often face is the transport of their wheelchair in their automobile. They may use their wheelchair in place of the manufacturer's car seat if they have a secure tie down system in their car. Still, the safest situation while riding in an automobile is to transfer into the car seat, but this causes the need to transport a wheelchair in the vehicle. This is often a problem because of the size and weight of most wheelchairs. Some wheelchairs have a cross-brace design so they can fold and take up less space, but they are heavier and do not propel and turn as well as the ultralight wheelchairs [3]. The ultralight wheelchairs may be lighter than depot wheelchairs but their frame cannot fold and they become difficult to load into an automobile. Either type of wheelchair creates difficulty for someone to lift it and place it in an automobile alone.

## STATEMENT OF PROBLEM AND RATIONALE

Accessing a seat on aircraft can be a difficult, time-consuming process for manual wheelchair users. Rigid frame manual wheelchairs are not easily stored in aircraft or automobiles. This may cause frustrating or impossible situations for manual wheelchair users. An ultralight wheelchair that is able to fold into a more compact transport size but still have the riding attributes of a rigid frame wheelchair would alleviate some of the complications involved with transporting a wheelchair on aircraft or an automobile. A wheelchair that is able to successfully transport someone into their seat without them having to transfer into another wheelchair and is able to fit in an overhead compartment of an airplane would improve airplane travel of users of manual wheelchairs.

## DEVICE DESIGN

The FFUWC uses the design concept of two interlocking triangles. One triangle represents the seat, the frame segment from the seat to the axle, and then the center strut from the axle to the front of the seat. The other triangle is formed of the chassis between the axle and the casters, the vertical supports for the front of the seat, and the center strut. The dimensions of the wheelchair in the most compact configuration was to be smaller than the size of an overhead compartment of an airplane, which is about 36"x 20"x 10". The wheelchair is modeled after Centers of Medicare and Medicaid Services definition of an ultralight wheelchair (HCPCS code K0005). The weight of the wheelchair was to weigh less than 30 lbs, have a seat depth of 16 in., have a seat width of 14, 16, or 18 in., and have a seat height from 17 to 21 in from the ground. Armrests have been omitted from the device design for now until the folding and adjustable features have been finalized.

Adjustable features were added after the first prototype had been successfully built. These adjustments include: backrest height, backrest angle, seat dump angle, and pushrim wheel axle position. The ranges of adjustability were determined from ranges of other ultralights. The adjustable features are designed to allow for intuitive adjustments with common tools. This will decrease wheelchair setup time for the clinician and user, without losing the fine adjustments needed for proper wheelchair setup.

## DEVELOPMENT

At the present time, two prototypes have been built. The first prototype FFUWC was built to the specifications asked for by a 55 kilogram experienced wheelchair user (Figures1, 2). It weighs 25 pounds and is able to fold and fit easily into an overhead compartment of an airplane. There is one place on the frame where a fastener must be removed in order to fold the wheelchair. One fastener has a quick release pin, much like that on quick release wheels, that must be removed from the seat strut under the seat pan. A spring-loaded fastener that can be released by pinching two pins and pushing the upside down U-shaped frame located in the front of wheelchair toward the wheel axles, aiding in folding the chair.

The second prototype was built using the same folding characteristics of the first prototype but this prototype incorporated a 16 inch wide seat and adjustability of the seat angle, backrest height, backrest angle, and axle position. The backrest height adjustment allows for a range of heights of 12 inches to 15 inches with increments of half of an inch adjustment. The backrest angle adjustment permits angles 0, 5, and 10 degrees from the vertical. The seat dump angle adjustment will allow for angles 0, 5, 10, and 15 from the horizontal. The multiple axle position allows for a range of three inches of horizontal adjustability and two positions an inch apart for vertical adjustability (Figure 3).

Chromium molybdenum alloy 4130 steel tubing is the standard tubing used in the aircraft industry and was used for the all the tubing on the frame of the prototypes. This alloy has high strength, which allows for small diameters and wall thicknesses to be used for the tubing. It is weldable and can be brazed successfully with high strength. The final result is a lightweight frame with high strength. Aluminum alloy 6061 was used for most other of the parts including the footrest, backrest, side guards, seat pan, and the axle/backrest interface plate. 6061 alloy has a high strength-to-weight ratio, high resistance to corrosion, and is easily machined. Except for the wheels, all parts were machined from common materials using conventional milling and computer numerically controlled milling.

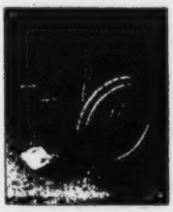
**Figure 1**: FFUWC in upright position

**Figure 2**: FFUWC in collapsible position

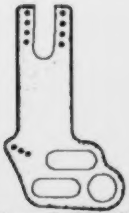
**Figure 3**: FFUWC adjustability plate

## EVALUATION

For over a year, the first prototype has been driven by the user. He has flown many times on commercial airlines without incident. He has been able to load it into the overhead compartment of all commercial jet aircraft, and to fit it into the suit closets. The wheelchair is functional in most aircraft lavatories for transatlantic or transpacific flights. The wheelchair fits down aircraft aisles of 15" width or greater. He has also transported the wheelchair in a variety of compact automobiles. The wheelchair stows easily in the trunk or a passenger seat.

The second FFUWC prototype was evaluated using the wheelchair standards developed by the American National Standards Institute and the Rehabilitation Engineering and Assistive Technology Society of North America (ANSI/RESNA). These standards are voluntary in the United States but they can be used as verification that the wheelchair is safe so that the manufacturers are less liable if a lawsuit is brought upon them [1]. The US Department of Veterans Affairs uses the results of this testing in purchasing decisions [2]. The results are also useful in the comparison studies of wheelchairs [1].

Parts 01, 05, 07, 08, and 93 of the ANSI/RESNA standards testing are the sections that apply to manual wheelchairs and were performed on the FFUWC [4]. Parts 05, 07, and 93 are the dimensional tests and the FFUWC either passed, if there was a pass/fail criterion, or had similar results to other ultralight wheelchairs, if there was no pass/fail criterion. Part 01 testing includes the static stability tests and the tipping angles found were acceptable for all axle positions of the FFUWC. Part 08 strength testing is composed of static, impact, and fatigue tests. The wheelchair passed all the static and impact tests but failed during fatigue testing. More specifically, the FFUWC's frame holding the caster's housings in place permanently deformed during the two-drum test (Figure 4) between the 5550th and 7600th cycle. The curb drop test could not be performed due to the failure, thus no results can be reported.

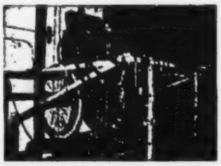

**Figure 4**: FFUWC on the two-drum testing device

## DISCUSSION

The ultimate goal of the FFUWC project is to create a marketable device that will allow for greater independence for people who use manual wheelchairs. Further progress is needed before the wheelchair can be considered a safe and marketable device. The first prototype FFUWC showed that a wheelchair could be built according to the specifications needed to allow it to be an ultralight wheelchair that can fit into an overhead compartment of typical aircraft. Also, the performance of the wheelchair is acceptable. The second prototype incorporated adjustability and allowed the wheelchair to be used by a broader population than before. The testing of the second prototype showed that some members of the frame needed to be redesigned to allow for higher fatigue strength. The next step will be to redesign the second prototype until it is able to pass both the double drum and curb drop tests. After completion of the tests, another prototype will be built that will allow for more features including: wheel camber, more axle adjustability, and a more compact folding design.

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# Mechanical Properties of Polyurethane Elastomers in an Oblique Angled Suspension Caster Fork for Wheelchairs

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## ABSTRACT

Suspension casters have been developed to dissipate shocks experienced during wheelchair driving. An important factor in the effectiveness of the caster is the type of elastomer used because it is the material that absorbs the majority of the shock. This study examined the durability of using polyurethane in suspension casters by considering the load-deformation and force-time properties of three hardnesses of elastomer under curb-impact testing conditions. The results indicated that polyurethane is a suitable material because it is available in hardnesses that support the forces in casters. It is also has acceptable fatigue behavior during the life of a wheelchair.

## BACKGROUND

Wheelchair rider comfort is important in avoiding secondary injuries due to extended wheelchair use. These secondary injuries can either be musculoskeletal injuries or neurological injuries [1]. When traveling over obstacles in a manual wheelchair, the resulting forces are transmitted from the casters and the wheels, through the frame and seat cushion to the body of the wheelchair user [2]. Vibration and impact forces can also be a factor in reducing fatigue life in wheelchairs, eventually leading to failure in the frame, at the welded joints, and in the casters, which would jeopardize the safety of the wheelchair. Frame failures top the list of engineering factors in wheelchairs in reports to the FDA [3]. To compensate for high and repeated forces and to dampen the shock from these forces, suspension casters have been designed. We have developed a caster that is able to absorb shock in the vertical and horizontal directions (Figure 1) [4]. When an obstacle hits the wheel, the caster rotates about the bolt that locks the two pieces together and along the curvature in the interface of the two pieces, creating a moment about this point. The elastomer is oriented tangential to the curvature of the interface and perpendicular to the path of rotation of the swing-arm about the pivot. Using this geometry, the reaction force creates only an axial force on the elastomer. The elastomer is then in compression and can dissipate the shock efficiently.

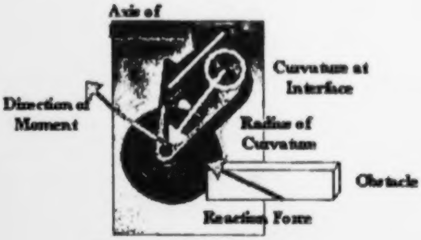


**Figure 1**: Oblique Angled Suspension Caster Fork

Creating a caster design that is more efficient in absorbing shock is only one step in reducing shock in the casters. An important consideration in absorbing shock is the type of elastomer used. While springs and other rubbers can be used, polyurethane's properties make it the most desirable to use in casters for wheelchairs. In general, polyurethane is a linear elastic material when exposed to compression loads [5]. It has greater energy absorption than similar rubbers and plastics [5]. Polyurethane is a very resilient material that can support heavy loads with minimum deflection and can recover completely after being loaded [5]. It is also virtually unaffected by common outdoor temperatures.

A wide range of hardnesses of polyurethane are available but no published research has been done to determine which are most appropriate for suspension caster use. In order to be appropriate for use in a caster, the elastomer must be able withstand an impact force and deflect enough to dissipate the shock. Also, it must not deflect too much so that a wheelchair user is dolphining on their casters. It must be noted that both of these considerations are dependent on the mass of user. Suspension casters must be effective for the life of the wheelchair. The elastomer must not fatigue or lose its mechanical properties during everyday use over five years.

## RESEARCH QUESTIONS

The objective of this study was to characterize the mechanical responses of three hardnesses of polyurethane elastomers in order to validate the use of polyurethane in suspension casters. Load-deflection curves and force-time curves were generated from testing measurements to understand the behavior of the elastomer.

**Objective 1:** Compare the load-deflection curves for the three polyurethane elastomers to understand the load-deflection relationship and how much deflection is observed in each elastomer at different loads. It was anticipated that all the elastomers will show a linear load-deflection relationship and that the selected elastomers are appropriate for suspension caster use.

**Objective 2:** Compare the force-time curves for the three polyurethane elastomers to understand the fatigue effects of them while testing the caster at a constant deflection. It was hypothesized that the reaction force will not decrease over the duration of the testing.

## METHODS

The testing involved two separate protocols. The first protocol investigated the load-deflection relationship of different elastomers used in the caster, whereas the second protocol investigated the fatigue effects of different elastomers. For both protocols, three polyurethane elastomers were tested with hardnesses of 40A, 60A, and 80A. "A" is a durameter scale that is used to measure the hardness of rubbers and polyurethanes. Shore A ranges from 10 to 95 and the higher number represents a harder material.

The load-deflection testing was performed according to how the casters are loaded during a caster impact test that is administered in the ANSI/RESNA standards testing. These parameters are used because they were designed to simulate everyday use. Cooper *et al* have shown that casters experience an impact force up to 1000 N when hitting a curb [6]. Using these parameters, appropriate loading conditions on the casters can be carried out.

A compression-testing device (Instron, United Kingdom) was used to load the caster. The Instron system includes hydraulically controlled indenter with a load cell, a control panel, and a computer. The computer interfaces the indenter and the control panel has two output ports, which provides voltage data on force and displacement. A solid mounting bracket was made to secure the caster to the table of the testing device (Figure 2). The caster was secured to the bracket but was able to rotate as it would on a wheelchair. Triangular waveforms can be programmed into the Instron to control either force or displacement and were used to perform the impacts needed to test the caster in the same way the two-drum test does.

For the load-deflection testing, the Instron was programmed to apply a force at 1.25 Hz. The forces tested were 111 N and 1446 N in 111 N increments, if possible. The two softer elastomers could of the higher forces because the caster displaced too much and the two aluminum parts touched. After the linear relationship between voltage and deflection was found, the deflection voltage was measured from the oscilloscope. A linear correlation was found for the paired force-deflection data.

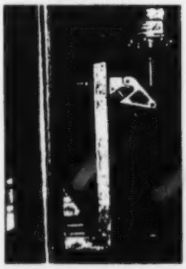


**Figure 2: Test setup**

The cyclic loading test was performed by programming the Instron to apply a known deflection and measuring the reaction force. For all three elastomers, a deflection of 10.2 mm was applied at a rate of 127 mm/sec with a frequency of 1.25Hz. This deflection is the amount of deflection at 1000 N of the hardest elastomer (80A). The caster and elastomer was tested at the same number cycles as the two-drum test. Force data was collected twenty equally spaced times (every 2.33 hrs) during the 200,000 cycles for seven seconds at a rate of 425 Hz. The peak forces within the seven-second sample were averaged and plotted with the other 19 samples in the time domain. The data of the three elastomers was then graphed and compared.

## RESULTS

The load-deflection curves for all three elastomers are plotted on one graph (Figure 3). Linear regression tests were run on the data from the 40A, 60A, and 80A elastomers and $r^2$ was found to be .9857, .9974, and .9976 respectively. All the elastomer force-time curves are charted on the same diagram (Figure 4). Linear regression tests were run on the data and all elastomers were found to have a very slight positive slope to their regression equation.

## DISCUSSION

In general, polyurethane has been shown to be an appropriate material to be used in suspension casters. The data agreed with the predictions made in both objectives. The load-deflection curves are highly linear which is predicted because polyurethane is known to be a linear elastic material [5]. The high linearity also indicates that the testing method for suspension casters presented is repeatable and accurate. It is important to notice that the hardness scale is not linear itself because the difference in slope between 80A and 60A is noticeably greater than the difference in slope between 60A and 40A. The data may be interpreted as to selecting an appropriate elastomer. For example a caster can experience a force of 1000 N on a two-drum test that uses a 100 kg dummy. According to the results for the 80A elastomer, this would indicate a deflection of 0.4 inches, which is half of the deflection that can be applied to this caster. Similarly, 40A deflects 10.2 mm for a 556 N user and 60A deflects 10.2 mm for a 667 N user. This also shows that the selected elastomers are appropriate for use in suspension casters.

The force-time curves indicate a near horizontal line for all three elastomers. Linear regression showed even a slight positive slope. This is caused due to the low force values seen in the beginning of the test. The low values are mostly likely a "settling" effect of the elastomer into the caster. Overall, the force-time curves demonstrate that the polyurethane elastomers do not fatigue after 200,000 cycles of loading similar to that experienced on the two-drum test. This indicates that the casters will be able to withstand the life of a wheelchair.

**Figure 3: Load-Deflection Testing**

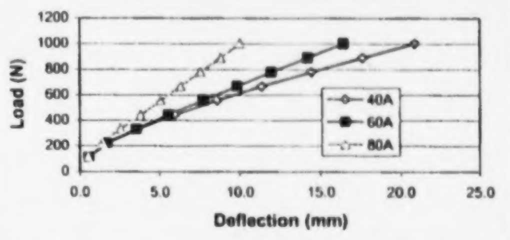
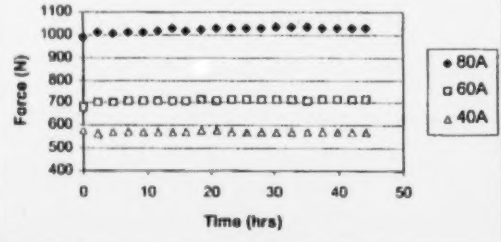


**Figure 4: Fatigue Testing**



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## ACKNOWLEDGEMENTS

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# ANALYSIS OF WHOLE-BODY VIBRATIONS OF SUSPENSION MANUAL WHEELCHAIRS: UTILIZATION OF THE ABSORBED POWER METHOD

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## ABSTRACT

Prolonged exposure to whole-body vibrations can cause secondary injuries to the musculoskeletal system in humans. In response to this, wheelchair companies have developed suspension wheelchairs. Six wheelchairs, three suspension and three cross brace non-suspension wheelchairs, were tested while descending two, four, and six inch curbs. Force and acceleration data were collected and absorbed power was calculated. Statistics show that there is no statistical difference ($p$>.083) between the absorbed power of the suspension wheelchairs to the cross brace non-suspension wheelchairs when descending curbs.

## BACKGROUND

Absorbed power is defined as "The power dissipated in a mechanical system as a result of an applied force"(1). In relationship to a manual wheelchair user, it is the amount of force (or vibration) that is transmitted to a user based on the forces that a wheelchair experiences during driving. Because wheelchair users make use of their wheelchairs as a primary mode of mobility, the prolonged exposure to transmitted forces can cause secondary injuries such as disc degeneration, and low-back pain (1). ISO-2631 (2) defines the parameters of transmitted vibrations, which can cause these secondary injuries, namely the magnitude of the vibrations and the time over which they occur.

Based on the exposure magnitudes of vibrations defined in the ISO-2631 standard, wheelchair companies added suspension to their wheelchairs to reduce the level of vibrations that are transmitted to a manual wheelchair user. Absorbed power is also a new method used in the analysis of whole-body vibrations and their effect on humans. Traditionally, the most employed methods of vibrations analysis were the vibrational dose value, the root mean square method, and the peak-to-peak method. A disadvantage of these methods is that they only measure the amount of acceleration of a vibrating surface (i.e. the wheelchair seat). The absorbed energy measure accounts for the contact between the surface and the user. Additionally, the energy is calculated directionally (vertical, horizontal, laterally) so a singular scalar power quantity can be defined by taking a resultant of the three directional vectors (3).

## RESEARCH QUESTION

Using the absorbed power method to evaluate the amount of whole-body vibrations that are transmitted to a manual wheelchair user, do suspension manual wheelchairs reduce these vibrations. These data are clinically important because they could present a justification to prescribe a suspension manual wheelchair over a non-suspension manual wheelchair to reduce to incidence of low-back pain and other secondary injuries.

## METHODS

A male with a spinal cord injury at the T7/8 level with over twenty years of manual wheelchair experience served as the test pilot in this study. The test pilot weighted 55 kg. Six manual wheelchairs were used in this study; three suspension wheelchairs, the Quickie XTR, Invacare A6S, and Colours Boing and three cross brace folding wheelchairs, the Invacare Action Xtra, E&J Epic, and Quickie 2. Each of the wheelchairs had similar rear wheels, similar casters, and similar critical dimensions (seat width, seat depth, backrest height, wheelbase, camber). Tires were inflated to their rated pressures and verified with a calibrated gauge.

Three sets of instrumentation were used to collect data from the tested system, a seat-plate accelerometer, bite-bar accelerometer, and the SMART$^{Hub}$. The seat-plate is a sixteen inch by sixteen inch by one-quarter inch aluminum plate instrumented with a tri-axial accelerometer and an angular rate sensor (ARS). The bite-bar also has an accelerometer and ARS and is made of surgical stainless steel and fits into the mouth using foam dental trays to protect the teeth. The SMART$^{Hub}$ is a device, which measures the amount of force experienced by the wheelchair at the rear wheel hub.

The test pilot was asked to descend three curbs of increasing height (50mm (2"), 100mm (4"), and 150mm (6")) (Figure 1). The landing for each curb was a concrete slab (i.e., building foundation). The test pilot was will be asked to stop and balance at the edge of each curb for a minimum of five seconds (i.e., minimal forward velocity). The test pilot rolled forward off of the curb in whichever way was most comfortable, in this case by doing a wheelie and descending the curb. Each sequence of curbs was randomly chosen and repeated three times with each chair. Subject used his personal cushions for all testing (in this case a Vicair Academy).

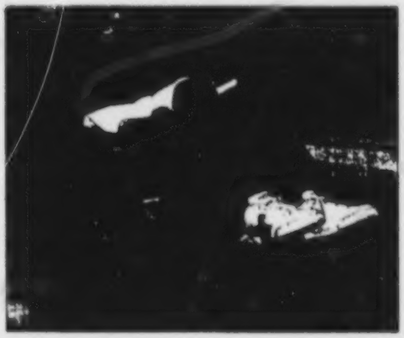

Figure 1 – Subject descending the 100 mm curb

Data were collected at 200 Hz, and filtered using a 100 Hz Butterworth Low-Pass Digital filter of 2$^{nd}$ order. Data were collected until the subject had negotiated all of the curbs. A Matlab program was written to determine the absorbed power of the system in the 4-8 Hz range corresponding to the area where humans are most sensitive to vibrations (1). A repeated measures ANOVA was done to analyze the data by type of wheelchair and by curb height.

It was hypothesized that as the wheelchairs descended the three curbs, data collected from the higher curbs will yield a higher absorbed power, and the suspension wheelchairs would yield a lower absorbed power than the cross brace frame wheelchairs.

## RESULTS

For each of the wheelchair types, the suspension wheelchairs and the non-suspension wheelchairs the absorbed power increased as the height of the curbs increased (Figure 2). Visually, the absorbed power of the suspension wheelchairs was less than that of the cross brace wheelchairs (Table 1). However the repeated measures ANOVA showed that the difference was not significant ($p$=.083)

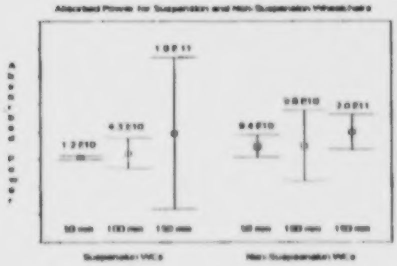

Figure 2 – Absorbed Power

|  | 2" Curb | 4" Curb | 6" Curb |
|---|---|---|---|
| Boing | 1.31E+10 | 9.40E+10 | 4.41E+11 |
| XTR | 1.70E+10 | 1.94E+10 | 9.50E+10 |
| A6S | 5.59E+09 | 1.60E+10 | 2.79E+10 |
| Epic | 8.64E+10 | 2.17E+11 | 1.40E+11 |
| Xtra | 6.51E+10 | 4.60E+10 | 2.26E+11 |
| Qu2 | 1.30E+11 | 3.10E+10 | 2.29E+11 |
| Suspension Avg | 1.19E+10 | 4.31E+10 | 1.88E+11 |
| Cross Brace Avg | 9.37E+10 | 9.81E+10 | 1.98E+11 |

Table 1 – Absorbed Power for 2,4, & 6" Curbs

## DISCUSSION

The repeated measures ANOVA showed no significant differences in absorbed power between the suspension wheelchairs and the cross brace non-suspension wheelchairs, although the data are approaching significance. This result might be accounted for because of the high standard deviation in the 150 mm curb for suspension wheelchairs and the 100 mm curb for the cross brace wheelchairs.

Based solely on visual comparison, there is a difference seen is the amount of absorbed power at each of the curbs. The absorbed powers of the suspension wheelchairs are less than the absorbed powers of the non-suspension wheelchairs at each of the curbs. The addition of more samples (i.e. another suspension wheelchair, another cross brace wheelchair, and rigid frame wheelchairs) might yield a significant difference in the wheelchairs.

## CONCLUSION

Although the current data appear to show that suspension manual wheelchairs are not significantly different than cross brace wheelchairs more data should be collected in order to be conclusive. Future studies should consider the inclusion of rigid manual wheelchairs, as well as additional suspension and cross brace wheelchairs.

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# WHEELCHAIR WHEEL WASH SYSTEM

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## ABSTRACT

When individuals confined to wheelchairs move in and out of their houses, their floor gets dirty. This is because dirt such as sand and mud stick to the treads of the large rear wheels of their wheelchairs. This presents an additional burden to their families since they have to clean carpets and floors each time these individuals get in and out from their houses. The purpose of this project is to present a solution to this problem by designing and constructing a manually activated wheelchair wheel wash system that allows an individual confined to a wheelchair to independently clean the large rear wheels of the wheelchair before going into the house. The unit that was constructed is portable. It consists of a frame that allows one rear wheel of the wheelchair to roll backwards into it. A roller system mounted on the frame allows the wheel to rotate freely by the individual only in one direction – backwards – against stationary brushes mounted on the frame. A water supply system attached to the frame aids in the cleaning process as the rear wheel rotates against the brushes.

## BACKGROUND

Many paraplegic individuals have no sensation below the nipple line, but do have good use of their upper body. These individuals are usually confined to a wheelchair and, at some point, face the nuisance of soiled rear wheelchair wheels. Any non-pavement excursion inevitably embeds dirt and sand in the treads of the tires. Currently, this problem is solved by both scrubbing and wiping down the wheelchair wheels with a rag and/or a brush. This is a tedious process that can take a long time to complete; and, if not completed thoroughly, dirt will be transferred to the individual's interior floor coverings. The goal of this project is to design and construct a unit that allows a paraplegic individual to clean the rear wheel of his/her wheelchair independently, and with a minimum effort.

## STATEMENT OF THE PROBLEM

A client desires a system that allows him to clean his rear wheelchair wheels. This system should satisfy the following criteria:

1. it should be independently operated
2. it should be easy and not tedious to operate
3. it should be compact in size, portable and lightweight
4. it should be used outdoors on a flat surface
5. it should be safe to operate
6. it should be virtually maintenance free

# WHEELCHAIR WHEEL WASH SYSTEM

## RATIONALE

The wheelchair wheel wash system was designed and constructed because there is not such a product that is currently available commercially on the market (1).

## DESIGN

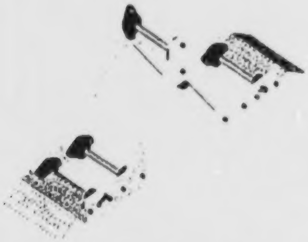

**Figure 1.** A 3-D AutoCAD drawing of the portable unit

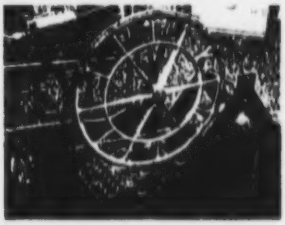

**Figure 2.** Picture showing the rear wheel of a wheelchair backed into the unit.

The design of the wheelchair wheel wash system was designed around a number of parameters. The main consideration was that the unit had to be mounted on a flat surface. It also had to be narrow enough so that when it was not being used it would not intrude in either the walkway of non-users, or the path of a wheelchair. The other parameters considered were that the system had to be lightweight, corrosive resistant, used predominately during the warm seasons, low cost, easy to use, and no maintenance.

The unit that was designed consists of a frame with a raised center section. Figure 1 shows a 3-D AutoCAD drawing of this frame. Only one rear wheel of a wheelchair is cleaned at a time by rolling backwards into the unit as shown in Figure 2. Once a wheel is confined to the unit, it sits on two rollers and backs against a third as shown in figures 1 and 2. The third roller acts as a stop to limit the backward motion of the wheel. Two stationary brushes are installed, one on each side of the raised section, as well as a garden hose water supply line and a water valve. Before the system is used the water supply may be turned on by a manual shutoff valve that is located on the frame. If the shutoff valve is put in the open position water flows through two adjustable hoses that spray water on the brushes. As the wheel rotates against the brush, dirt and/or sand are scrubbed off the wheel and flushed away by the running water.

The rollers are made of 6061-T6 aluminum and are ¾" in diameter. This diameter is small enough so that the wheelchair would not be unstable while the wheel is supported by the rollers. Once in the unit, the wheelchair wheel is elevated only 1-5/16" off the ground. The 6061-T6 aluminum is relatively lightweight and offers good corrosion resistance. Rollers design was performed based on two loading conditions simulating the two most critical situations. The first situation is that the client will enter the unit directly in the center of the roller, creating maximum bending stress, which was calculated to be 5,690 psi. The second situation is where the client enters the unit with his rear wheel as close as possible to the bearing housing. This results in the maximum shear force, which was found to be 96.5 lbs (2).

The frame is also made of 6061-T6 aluminum due to its resistance to corrosion and its low density. Each side of the frame consists of five pieces, each 3" wide and ½" thick, that are welded together using double vee pass butt weld. In order to extend the life and intervals of maintenance of the wash system, the design utilizes two-bolt composite flange bearings developed for the food service industry. These sealed bearings are stainless steel, surrounded by a composite body. These bearings are rated at a static radial load of 1,470 lbs. which is well above the maximum load of 96.5lbs the bearing will be subjected to (3). No dynamic loading was considered due to the slow speed at which the roller will be rotating.

In order to get out of the unit, the front roller is allowed to rotate in only one direction, namely the direction that allows the wheel to move backward. As the user is ready to move away from the unit, he/she will push the wheel of his/her wheelchair forward causing the front roller to lock in place and the wheelchair wheel to climb over the front roller and onto a diamond plate access ramp. This ramp is attached to the frame and makes 30 degrees with the floor, allowing thus a smoother entry and exit to and from the unit.

## EVALUATION

The unit was tested and appears to function appropriately: the system of rollers allowed the rear wheel of a wheelchair to be pushed against the brushes and to rotate only in one direction – backwards as it is cleaned. Cleaning dirt from the rear wheel is accomplished by a combination of water being sprayed onto the brushes and the rear wheel being rotated. As a user exits the unit, the roller locking mechanism effectively locks the front roller allowing the rear wheel to rotate forward. The unit access ramp was effective in allowing easy entry and exit to and from the wheel wash unit.

## DISCUSSION

The unit that was designed and constructed allows a paraplegic individual to clean the rear wheels of his wheelchair with no effort by washing out mud and sand from them before going into the house. The unit is compact in size, and when rigidly attached to the home entrance ramp, it is narrow enough to allow for a wide passing area by the wheelchair when the unit is not needed and by other non-users who are just trying to get in and out of the front door. The unit is also portable, which allows for seasonal use. Such a device improves the quality of life and allows for more independence for disabled individuals. The total cost of the parts was about $800. This appears to be high but it could be drastically reduced in mass production. The unit includes 10 bearings, each costing about $50.00. If this product is to be commercialized, the costs of the bearings will be drastically reduced, reducing thus the total costs to manufacture the unit.

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# A SYSTEMATIC PROCESS FOR SUCCESSFUL TECHNOLOGY TRANSFER

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## ABSTRACT

The Rehabilitation Engineering Research Center on Technology Transfer ($T^2$RERC) is developing, implementing and testing systematic models of technology transfer. Starting in October 1998, the $T^2$RERC partnered with the Rehabilitation Engineering Research Center on Wheeled Mobility to conduct the *Demand-Pull Project on Wheeled Mobility*. This Project facilitates the transfer of technology and introduction of products into the wheeled mobility marketplace that address high-priority needs of consumers and other stakeholders. Successful transfers to date include a marketed power management technology (PowerCheq™ from Power Designers Corporation), a start up power wheelchair company, a start up lever drive manual wheelchair company and multiple manufacturers seeking to extend their product lines into the wheeled mobility marketplace.

## BACKGROUND

Technology transfer is the application of existing technologies in new or novel applications (1). Past efforts to systematically transfer technology in the field of assistive technology have not been successful (2). The $T^2$RERC is developing, implementing and testing models of systematic technology transfer. The objective is to conclusively determine whether technology transfer can be a deliberate and successful process, or whether it is best left to occasional cases of serendipity. Starting in October 1998, the $T^2$RERC partnered with the Rehabilitation Engineering Research Center on Wheeled Mobility to conduct the *Demand-Pull Project on Wheeled Mobility*. Demand Pull technology transfer begins by identifying unmet customer needs and then seeking technology solutions that address these needs (3). For this Project, we identified and pursued the highest priority, long-standing and unresolved limitations for the Wheeled Mobility Industry.

## METHOD

The Project can be stated in six steps each with distinct activities and outcomes. Below, **Step C** activities include "running a Stakeholders Forum and data analysis" while **Step C** outcomes include "a series of problem statements for needed technologies."

**Select Industry Segment (10/98)** – Initial Project focus (candidate customer needs, candidate technology needs) is established in partnership with the RERC on Wheeled Mobility.
**Conduct Market Research (11/98-2/99)** - A comprehensive industry profile is developed. Consumer panels and interviews with researchers and manufacturers are conducted. Information from consumers, manufacturers, and researchers is triangulated to establish priority market and technology needs.
**Validate Market Research (3/99-8/99)** - A "Stakeholders Forum," is used to validate customer needs, "confirm" that manufacturers cannot independently acquire or develop needed technologies, and establish performance targets for needed technologies. The Forum with about 70 participants had balanced representation from all stakeholder groups. Problem Statements were developed in four technology areas that summarized business opportunities and performance requirements for technology solutions:

Power Management and Monitoring (e.g. power gauge – indicates battery power and health, digital interface visible in the dark, approximate range in hours and miles, etc; power management - increased range and time between battery charge, increased battery life, etc)
Manual Wheelchair Propulsion (e.g. geared hubs - multi-speed, geared in forward and reverse, user selectable gear ratio, retain standard push rim, etc)
Advanced Motors and Drive Trains (e.g. motor with electronic transmission capability - high efficiency at all speeds, high starting torque, electronic transmission capability, etc)
Materials and Components (e.g. non-marking tires - conductive, long wear, puncture proof / puncture resistant, high traction in all weather and on all surfaces, etc)
**Disseminate Problem Statements (10/99-Present)** - Active solicitation: contact technology developers directly, or via the Federal Laboratory Consortium Locator Service, University Technology Transfer Offices, etc; Passive dissemination: websites, NASA Technical Briefs, FLC NEWSLink, flyers, etc.
**Broker Technology Transfer (11/99-Present)** – Proposal submissions are screened and a marketing plan and commercialization package developed for promising proposals. Technology transfer success hinges on development of a unique and specific marketing plan for each technology. This plan must account for the desires of the technology developer, the state of the technology (e.g. concept, prototype, finished product), and the express or implied needs of the target customers. Manufacturers are contacted and transfer negotiations facilitated. Transfer mechanisms include: sales through distributors and exclusive or non-exclusive technology license, R&D, OEM or Cooperative Research and Development Agreements.
**Expand Commercialization (10/01-Present)** – Support for market broadening, strategic leveraging, product line extension, business plan development for technology developer.

## OUTCOMES

We have received viable solutions to all four problem statements. One solution for power management has already transferred to the marketplace (see case study below).

*Case Study: The PowerDesigners "Power Check™"* – PowerDesigners, a small, high tech engineering company associated with the University at Wisconsin, first became aware of the Project via an abstract in the August 2000 NASA Technical Briefs: Readers Forum. In 9/00, Power Designers submitted a proposal for the "PowerCheq™ - a modular, bi-directional battery string equalizer that uses a patented algorithm to ensure that all batteries within a string are kept at the same charge level - never over or undercharged. This enhances battery string performance allowing for longer battery life (approximately double), longer run time and increased battery capacity." In 1/01 the proposal was screened and accepted. In 2/01 a commercialization package was developed and marketing to mobility product manufacturers begun. In 3/01 Power Designers conducts performance tests of the PowerCheq™ on batteries used with power wheelchairs and scooters - test results were very positive. In 6/01, Amigo Mobility showed interest in the PowerCheq™ and began independent performance testing. In 9/01 PowerDesigners became a non-exclusive Original Equipment Manufacturer (OEM) for Amigo. The PowerCheq™ will be standard equipment on some Amigo Scooter lines marketed Fall 2001. From 9/01-present, PowerDesigners has become a non-exclusive OEM for Bruno Independent Living Aids (for wheelchair lifts) and Pride Mobility Products Corporation (for wheelchairs and scooters). Several other manufacturers are in negotiations and the T2RERC is helping Power Designers as they develop product line extensions.

*Other transfer activities* resulting from this Project include:

Helixsphere (a Canadian company) is currently developing a lever-driven manual wheelchair under a grant (analogous to a Phase II SBIR) from the Canadian government

The T2RERC is providing market research, supporting business plan development, and seeking investors for a startup wheelchair company (further information is proprietary)

The T2RERC is working with a number manufacturers interested in becoming OEMs for the wheelchair and scooter industry: advanced power monitors (several), advanced tire materials and design (1, an RERC on Wheeled Mobility referral), and advanced alternative power supply (1).

At the time of this writing, the Demand Pull Project on Wheeled Mobility had just reached its three-year anniversary from date of inception. Approximately 32 different technology developers have submitted one or more proposals. There have been a total of 641 person-days (p-days) invested in this Project – roughly one full time equivalent (FTE) person for each of the three years. Staffing for the Project includes a mix of university faculty, professional staff and graduate students. Time investment can be further broken down by activity (% of total investment, person-days) as: Select Industry Segment (1%, 8.8 p-days), Identify Technology Needs (23%, 147.2 p-days), Validate Technology Needs (33%, 211.1 p-days), Locate Technology Solution (9%, 56.6 p-days), Market and Transfer Technology Solution (33%, 211.1 p-days), and Expand Commercialization of Technology Solution (1%, 6.0 p-days).

## DISCUSSION

Information derived from the Mobility Project is being used to improve subsequent Projects. For instance, the question "how did technology developers become aware of the Project? (Approximately 43% via the FLC Locator Service, FLC NEWSLink or direct mailings to Federal Labs; 40% via NASA Technical Briefs; 10% via 'search hits' on the Project Website; 3% via direct solicitation; 3% via referrals)" suggests which dissemination vehicles have been most effective and how dissemination might be improved. The question "where did technology proposals come from? (Approximately 63% small companies, 30% Federal Labs, 3% private inventors, 3% large companies, 0% universities)" helps identify "rich" technology sources (given the dissemination vehicles employed) and suggests which technology sources might be better "mined." The Mobility Project deliberately targeted the Federal Laboratories in its dissemination approach and many of the small companies submitting proposals are somehow affiliated with universities or Federal Laboratories. Current Projects have expanded dissemination by soliciting proposals from major research universities (direct solicitation to researchers and facilitated solicitation in partnership with university technology transfer offices). A comparison of the Demand-Pull Technology Transfer Project to Federally supported SBIR programs in terms of costs, timeframes and efficiency and many additional results are written up in the RERC on Technology Transfer State of the Science Conference Proceedings (4).

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# CONSUMER PREFERENCES FOR WHEELCHAIR WHEELS

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## ABSTRACT

Wheelchair manufacturers provide a variety of wheel options for manual wheelchairs. Clinicians and consumers are commonly provided with confusing information about the potential benefits and features of new wheel designs. The purpose of this study was to determine the preferences of manual wheelchair users for a selection of wheels. Six types of wheelchair wheels were presented to subjects to obtain information regarding their impression of the wheels. Composite MAG and steel spoked wheels were presented with the less common X-Core, OX High Density Carbon Fiber, Spider ™, and Spinergy wheels. Data regarding the subjects' impression of the wheels appearance, durability, and impact on ride comfort were obtained. The results indicate that Subjects base much of their preference on appearance. The subjects tended to prefer the non-standard wheels. This data is important to determine whether we are meeting the consumers needs, and to develop specifications for wheels.

## INTRODUCTION

There is a paucity of data about consumer satisfaction with manual wheelchairs and their component parts. As consumer satisfaction for their manual wheelchair is typically viewed as a whole. If there is something that could be done to improve upon a part of the wheelchair consumer satisfaction may increase. In an age where Medicare and other third-party payers influence policies regarding the prescription of a wheelchair, the component parts are under increasing scrutiny. Thus, the individual prescribing the wheelchair for the client may recommend the least costly and "standard" options in order to avoid having the wheelchair denied by third party payers.

While knowing the weight of the entire wheelchair may influence the decision to purchase a standard depot style wheelchair or a lightweight manual wheelchair, knowing the weight of each removable component part may also influence the selection process (1). The weight of the wheelchair may also influence the manual wheelchair user's or attendant's abilities to lift the wheelchair when transporting the device. When assessing the weight of a manual wheelchair using the ANSI/RESNA standards, the total weight of the wheelchair equipped with standard armrests, wheels, legrests, and casters is measured (1). In addition, the selection of the component parts is often left to what is least costly and minimizes the overall cost of the wheelchair. Information regarding the appearance is important to consumers, but is often much lower in importance to insurers (2). As consumers and end users for these products the opinion and suggestions of the manual wheelchair user should be taken into account.

## RESEARCH QUESTION

Consumers may be unaware of the options for various types of wheels available for manual wheelchairs. This study examined the preferences for selected wheels based upon a sample of manual wheelchair users. We were interested in learning if the wheels commonly provided are similar to those preferred by consumers.

## METHODS

Design and Participants: Ten manual wheelchair users were recruited from the VA Pittsburgh Healthcare System Seating Clinic and the Human Engineering Research Laboratories. Seven subjects had ultralightweight (Medicare K005 code) wheelchairs while 3 subjects had depot style (K001 code) manual wheelchairs. Six subjects had steel spoked wheels, 3 subjects had composite MAG wheels, 1 subject had X-Core wheels.

## RESULTS

A Likert scale was utilized to determine how much the subjects' liked each of the wheels. A repeated measures ANOVA was then calculated to determine the p-values for each variable.

There does not appear to be a significant relationship for subjects' opinion on the ease of removal (p= .54) of the wheels and whether they would elect to use the wheels when traveling on rugged terrain (p=.33). There was a significant difference when asked which wheel the subject liked (p=.002) and disliked (p=.004) based upon appearance, as well as, whether they would use the wheels when going to a social event (p=.036). When comparing the type of wheel that each subject used versus which wheel the subject favored for appearance (p=.58), ease of removal (p=.14) and ride comfort (p=.18) there was not a significant difference. Likewise, when comparing the subject's current wheel to the wheel that they disliked based on appearance (p=.58) and least comfortable ride (p=.84) there was not a significant difference. Subjects were also asked to indicate which wheel they liked the best and the least (Table 2.0). Overall, subjects (n=6) preferred the appearance of the X-core wheels and disliked the appearance of the steel spoked wheels (n=5) when comparing all of the wheels.

| | **Decon Spider™** | **Spinergy** | **OX High density** | **X-Core** | **Steel Spoked** | **MAG** |
|---|---|---|---|---|---|---|
| **Appearance- like** | 1 | 2 | 0 | 6 | 1 | 0 |
| **Durability- like** | 3 | 1 | 0 | 3 | 2 | 1 |
| **Ease of removal-like** | 2 | 3 | 1 | 3 | 1 | 0 |
| **Ride Comfort- like** | 2 | 2 | 0 | 3 | 3 | 0 |
| **Appearance- dislike** | 2 | 0 | 2 | 1 | 5 | 0 |
| **Durability- dislike *** | 1 | 0 | 3 | 1 | 3 | 1 |
| **Ride Comfort- dislike** | 1 | 2 | 3 | 0 | 3 | 1 |

Table 2.0 Subject's Preference of Wheels Based Upon Appearance, Durability, and Perceived Ride Comfort (N=10) * One subject did **NOT** report on Durability- dislike.

## DISCUSSION

The recommendation of a manual wheelchair or any of its' component parts are typically made by a clinician or a rehabilitation technology supplier (RTS). The consumer collaborates with the clinician or RTS regarding which device he or she ultimately wants to pursue but it is not typically the consumer's objective to pick out point by point each item in the specification of the device. The consumer does have the right to do so if he or she chooses. For those individuals who do not wish to pursue a high end or ultralight wheelchair, the choices have been limited to spoked or composite MAG wheels as these are considered standard features. Purchasing the Spinergy® wheels costs about $550 when compared to purchasing spoked or composite MAG wheels which are cited as standard items and do not add to the overall purchase price of the wheelchair. As there was a significant difference in perceived appearance of the wheelchair wheels and not a significant difference in looking at perceived durability or ride comfort, demonstrates that consumers are interested in how the wheels look.

This study provides some of the first data on subject's opinion on the type of wheels they prefer. The results have some important implications for the design and selection of wheelchair wheels and the wheelchair itself. In the mid-1970's the wheelchair industry was challenged by the consumers demands for a lighter weight, better performing manual wheelchair. With the consumers needs not being heard or met by the wheelchair manufactures that dominated the industry at that time, new companies began to arise. Listening to the consumers concerns, these companies were instrumental in the development of revolutionary features, such as solid front casters, quick release axles, and adjustable axle positions (3). As the consumers' voice was heard during this revolution of sorts in the late 70's and early 80's, the results are important to ascertain whether or not we are still listening and meeting the consumers' needs.

Despite not being a significant difference, it is important to note that when looking at appearance, durability, ease of removal, and ride comfort as a whole, the X-core wheels prevailed as the favorable wheel as indicated in Table 1.0. Future studies should collect data regarding the consumer knowledge regarding his or her wheelchair, as well as, how the device was prescribed or purchased (i.e. clinician assessment; walk-in purchase). In addition, future studies may collect data after the subject has the opportunity to "test out" the product for himself. Durability testing is also necessary to better assess this feature of the wheels.

## CONCLUSION

The wheelchair wheels typically purchased today are either steel spoked or composite MAG wheels. Feedback from the manual wheelchair user tends to favor alternate types of wheels when provided with a selection. Consumers tend to base their favorite selection based upon appearance alone when not provided with information on durability, ride comfort, and ease of removal. There appears to be an adequate array of choices for consumers but there appears tobe a lack knowledge in what is available.

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**List of Suppliers**

1. Invacare Corporation, One Invacare Way, Elyria, OH 44036
2. OX Engineering Co., Ltd., 2186-1 Nakata-cho, Wakaba-Ku, Chiba-shi, Chiba-ken, 265-0043 JAPAN
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# WHEELCHAIR GARAGE ACCESS SYSTEM

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## ABSTRACT

The wheelchair garage access system project involved the design and fabrication of a wheelchair lift to be used by a paraplegic man. The lift was needed to safely raise and lower the client from his garage to the first floor of his house. Safety was the main objective of this project, as well as accommodating for any of the client's needs. Modification of the entryway was needed before the lift could be installed. The lift resembles a "forklift" design that consists of a steel platform powered by a single linear actuator, mounted on one side of the platform. The installation of this lift has provided the client with a level of independence greater than that which he had previously.

## BACKGROUND

Our client, a paraplegic individual, has full use of his arms and currently lives in his parent's home. The house is a tri-level home, where the main door opens to the second floor and the garage door opens to the first floor, which is below ground by approximately two feet. Before the lift was built, the client entered and exited the home from the main door using a long ramp in the front of the house. This was highly inconvenient for him and his family since he had to enter the house from the second floor that consists only of a living room, dining room and kitchen. No bathrooms are available on this second floor. Because of this, his family wanted to move him to the first floor where he could have his living room and bathroom contained in one area. The only way that the client could access the first floor independently was through the relatively elevated garage. In order to accomplish this goal, the entryway to the first floor from the garage had to be modified. A lift system was then designed and installed to help the client live more independently.

## STATEMENT OF THE PROBLEM

To allow the client to independently access his home, the group designed and fabricated a lift that could be used by a paraplegic individual and was easy to install in the current living environment. The lift was designed with the safety of the client as number one priority. The entryway did not allow adequate space for the wheelchair, and therefore was modified. In addition to the safety and usage requirements, it was the group's goal to make the lift marketable, manufacturable, and economical for today's use.

## IDENTIFYING THE PROBLEM

Before identifying the problem, many factors and limitations had to be fully understood in order to begin brainstorming solutions. The number one concern was the safety of the client, so the group had to ensure that they addressed all possible safety issues when considering solutions. The team also decided that the design should be easy to use for the client and accommodate his needs as well as those of his family. With these ideas in mind, brainstorming sessions were utilized to decide how all of these concerns would come together to resolve the problem.

## DECISION PROCESS FOR THE PROPOSED SOLUTION

The last design that was brainstormed was a "forklift" design. This design uses very little material, is compact for space saving capabilities, and would be very efficient in operation. However, this design also included some home modification and the availability of donated parts. Because this design was comparable to a forklift, the group observed lifts that were proven to work under greater stress loads than what this design was subjected to. This enabled the group to use an actual forklift as a template for them to compare their design.

The group decided to mount the linear actuator on the side of the lift, next to the wall of the garage. The actuator used is self-contained, where the oil reservoir, motor, microprocessor, bore, and stroke are all contained within the same unit. The actuator will be powered by a twelve-volt car battery, which is housed away from the unit. The battery will be connected to an automatic battery charger at all times, providing continuous power to the actuator. An automatic locking mechanism is contained within the actuator. When movement of the lift stops, a series of check valves automatically close to stop fluid flow. This keeps the actuator locked in its current position and also allows it to act as an emergency stop.

As an added safety feature, a limit switch was placed at the top and bottom of the stroke of the lift in order to ensure that the lift stopped at the correct location in the up and down positions. This would ensure the client does not stop the lift too high or low from the desired location in order to give him easy access on and off the lift.

## DESIGN AND ANALYSIS

The design itself consisted of two main components, a vertical guide, which is anchored to the ground and wall, and the moveable platform. The vertical guide acts as the support for the whole lift system and is the only portion of the lift in contact with the ground. The linear actuator powers the platform, the part in motion. The platform was constructed from 1.5"x 1.5" x 0.1875" steel tubing, while the vertical guide was constructed using 2" x 2" x 0.1875" steel tubing and 1" steel rods.

Oil impregnated bronze flanged sleeve bearings were utilized in between the vertical guide and platform to eliminate any friction between the vertical guide and platform. SolidWorks software was used to see spatial relationships of components and to ensure the lift would fit in the modified entry.

Mounting the lift into its permanent position was done by lagging the base frame to the floor, as well as joining the two base frame supports and anchoring them into the wall.

The drawing of the lift was created using SolidWorks and is shown in Figure 1 below in its lowered position. Calculations and Finite Element Analysis were done on the actuator-mounting pin, the connecting brace between the two platform frame supports, and the platform itself, to ensure that the stresses and deflection will fall within a reasonable factor of safety.

## EVALUATION AND DISCUSSION

This design proved to be very effective. However, the group decided that some modifications and changes would be made if they had to start all over again. For example, the group "over-designed" the lift based upon time constraints and availability of parts. The lift could have been designed using smaller gage steel and still have a reasonable factor of safety.

Completion of this project provided the group with a great sense of pride. They designed and fabricated a lift, from the ground up, that was used to help make a person's life easier by allowing him to live more independently. They also eliminated any and all pinch points, made the lift look visually pleasing, and mounted a control switch for the client. This project allowed the group to envision what work as a real engineer is like. Engineers solve problems. In the case of this group, they solved a problem and made someone else's life easier and more enjoyable in the process.

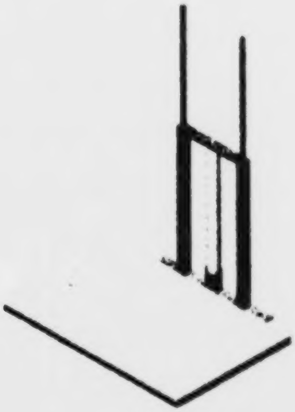

**Figure 1**

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# DISTURBANCES INDUCED BY WHEELCHAIR CASTERS WHEN DRIVING BACKWARDS

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## ABSTRACT

The purpose of the study was to examine the influence of three caster orientations on the reverse stability of an electrical-powered wheelchair. Forces and moments acting on the right and left casters were recorded by AMTI force plates placed underneath the casters. A total of 27 trials (three caster orientations, three driving speeds, three trials of each) have been collected. Peak force and moment values were identified for each case and ensemble force and moment curves are plotted. The results of this study indicate that caster disturbances are lower when both caster wheels orient straight backward at the start of reverse driving.

## INTRODUCTION

Many users of electrical-powered wheelchairs (EPWs) are challenged when driving the wheelchair backwards, especially in confined areas (e.g. the bathroom) [1]. It is reported that twenty-five percent of tips and falls occurred while the EPW was reversing [2]. There is no doubt that these accidents could be reduced and the use of an EPW be made safer during reverse driving, if the causes of reverse instability were known. The EPW reverse instability may be caused by a number of factors including the user, environment, speed, caster wheel orientation. The characterization of EPW reverse instability has not yet been fully explored. Rear wheel drive wheelchairs with front casters often exhibit directional instability while driving backwards due to the dynamics of the vehicles and the use of the back electromotive force (EMF) as a means of measuring the wheel speed for the feedback control [3]. The back EMF signal is inherently noisy at low speeds and the front caster orientations may cause abrupt side to side bucking or swaying of the EPW. The purpose of this study was to investigate the disturbances induced by three caster orientations at the start of backwards driving at three different speeds and thus examine patterns for developing improved controls. To date, no such characterization study has been published and no literature linking caster wheel orientations to EPW reverse stability exists.

## METHODS

In order to characterize the reverse stability, 3-D ground reaction forces and moments acting on the left and right casters at the start of backwards driving were collected. A 75kg Hybrid II test dummy was used to simulate a person driving the wheelchair (Quickie P100). A joystick template attached to the joystick housing was designed to ensure that the wheelchair received a command to move straight backwards and maintained a consistent speed throughout trials by providing a step input. A wooden platform was constructed to house the Advanced Mechanical Technology, Inc (AMTI) force plates, which sit flush within the platform to ensure a level surface and were used to collect kinetic data, i.e. forces and moments. Two force plates were positioned directly underneath the right and left casters. Three force components along the XYZ axes and three moment components about the XYZ axes, where the positive-Z axis points down, were recorded with a VXI computer system (Hewlett-Packard).

The test protocol included three caster orientations at the start of backwards driving, i.e. P, Q and U, and three driving speeds, i.e. fast (1m/s), medium (0.5m/s) and slow (0.25m/s). At the P orientation (Fig. 1), both the right and the left caster wheels oriented forward. At the Q orientation (Fig. 2), the right caster wheel oriented 90 degrees left and the left caster wheel oriented 90 degrees right. At the U orientation (Fig. 3), both caster wheels oriented straight backward. Three trials for each caster orientation were performed at each driving speed. A total of 27 trials were collected and analyzed.

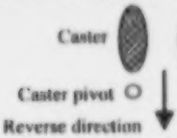

Fig. 1. P orientation

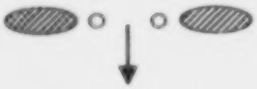

Fig. 2. Q orientation

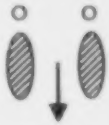

Fig. 3. U orientation

## RESULTS

For each caster orientation and driving speed, the average of peak forces and moments acting on the right and left wheel casters for three trials were obtained (Table 1). The ensemble average force and moment curves are shown in Fig. 4, Fig. 5 and Fig. 6 for three caster orientations P, Q and U respectively at the fast driving speed. Fig. 7, Fig. 8 and Fig. 9 show the ensemble average force and moment curves at three driving speeds respectively when the casters are aligned at the P orientation.

**Table 1: Peak Forces and Moments Acting on the Casters in the Reverse Driving with Different Initial Caster Orientations and Speeds**

| | Fast Speed | | | | Medium Speed | | | | Slow Speed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P Orientation | | | | P Orientation | | | | P Orientation | | | |
| | Rf* | Rm* | Lf** | Lm** | Rf | Rm | Lf | Lm | Rf | Rm | Lf | Lm |
| x | 177.3 | 158.5 | 182.3 | 121.2 | 182.3 | 151.0 | 180.8 | 116.8 | 188.7 | 163.1 | 175.3 | 121.4 |
| y | 205.8 | 113.7 | 199.2 | 85.4 | 216.4 | 115.7 | 188.6 | 86.7 | 202.7 | 104.8 | 193.7 | 84.9 |
| z | 1051.3 | 48.3 | 927.2 | 42.1 | 1049.3 | 48.6 | 903.6 | 41.8 | 1053.2 | 46.9 | 891.8 | 42.3 |
| | Q Orientation | | | | Q Orientation | | | | Q Orientation | | | |
| x | 164.4 | 155.9 | 205.1 | 122.5 | 165.4 | 151.0 | 188.2 | 120.2 | 164.9 | 150.7 | 188.2 | 123.0 |
| y | 226.4 | 133.8 | 208.8 | 82.8 | 233.0 | 112.4 | 212.3 | 82.6 | 227.4 | 123.4 | 207.8 | 82.6 |
| z | 1019.8 | 50.1 | 891.8 | 55.7 | 1000.1 | 49.3 | 903.6 | 42.7 | 994.2 | 47.9 | 878.0 | 42.1 |
| | U Orientation | | | | U Orientation | | | | U Orientation | | | |
| x | 170.4 | 159.3 | 177.8 | 120.7 | 182.8 | 150.7 | 180.8 | 140.9 | 178.3 | 149.2 | 171.9 | 120.7 |
| y | 188.1 | 97.6 | 186.6 | 109.1 | 185.6 | 98.7 | 180.5 | 113.9 | 183.1 | 99.7 | 180.0 | 82.6 |
| z | 1011.9 | 50.3 | 880.0 | 41.3 | 998.1 | 48.3 | 870.1 | 41.6 | 994.2 | 46.8 | 862.3 | 41.7 |

* Rf=right caster force (N), Rm= right caster moment (N.m);
**Lf=left caster force (N), Lm=left caster moment (N.m).

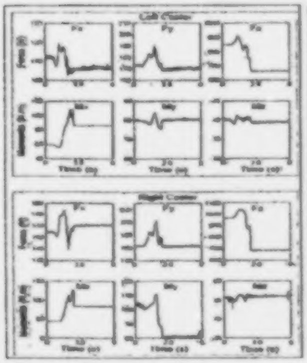

Fig. 4. Forces and moments at P caster orientation

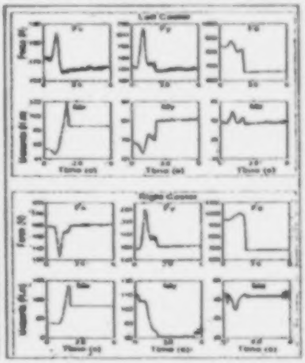

Fig. 5. Forces and moments at Q caster orientation

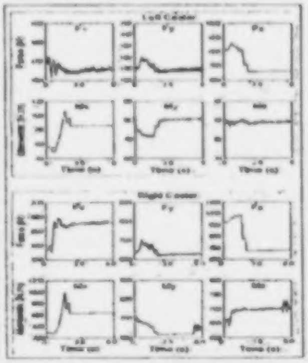

Fig. 6. Forces and moments at U caster orientation

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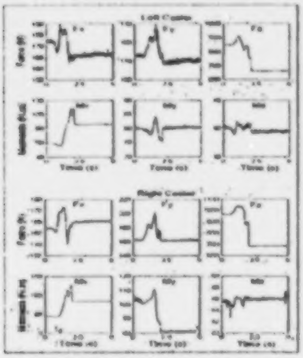

Fig. 7. Forces and moments at the fast speed

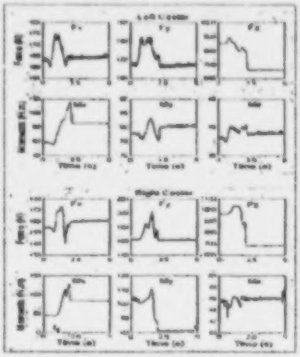

Fig. 8. Forces and moments at the medium speed

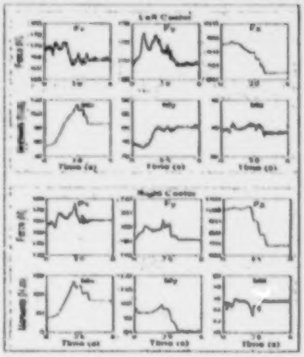

Fig. 9. Forces and moments at the slow speed

## DISCUSSION

The greater stability of an EPW is characterized by the low force and moment values recorded by the force plates underneath the caster wheels. Especially, large force components along XY axes and moments about Z axis can result in twisting or swaying of an EPW. From Table 1, it is found that for the same driving speed, peak forces and moments at the U caster orientation tend to be smaller than those values at the other two caster orientations, though a few exceptions occur. From the force and moment curves shown in Fig. 4 to Fig. 6, a similar conclusion can be drawn that caster disturbances are lower with the U orientation at the start of reverse driving, as the corresponding force and moment curves are much smoother than those of the others and particularly the curves of forces along XY axes and moments about Z axis go well without abrupt drops or rises. In addition, the disturbances induced by the P orientation are smaller than that by the Q orientation, for the force and moments curves at the P orientation go smoother with lower peak values. It should be noted that all the figures are plotted using the same scale so that the differences can be visualized immediately. From Fig 7 to Fig 9, the effects of three driving speeds on the reverse stability are examined at the same caster orientation. The result is a little bit surprising, as the force and moment curves for each driving speed show similar shapes and peak values and thus driving speeds may play a minor role in determining caster disturbances during the reverse driving.

Future work will be conducted on testing more wheelchairs and eventually lead to the development of control algorithms to dampen or eradicate the reverse instability. The finding of this study may also be useful to teach caster management in order to control the casters from precariously orienting, ultimately leading to the reduction of rearward driving accidents.

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# DURABILITY AND VALUE OF POWERED WHEELCHAIRS

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## ABSTRACT

Currently limited data comparing the quality of powered wheelchairs exist. The durability and value (cost-effectiveness) of the Pride Healthcare Jazzy 1100, the Sunrise Medical Quickie P200, and the Permobil Chairman ($n=9$) were tested using the ANSI/RESNA standards and the results were compared. Results showed significant differences in value ($p=.027$) and no significant differences in the durability ($p=.061$). The Pride Healthcare wheelchairs had the highest mean value and durability, and the Permobil wheelchairs had the lowest mean value and durability. This information can help both clinicians and consumers select robust and economical wheelchairs.

## BACKGROUND

Clinicians need reliable data about durability and value (cost-effectiveness) of power wheelchairs available to help consumers select high quality, appropriate products. Wheelchairs that require excessive maintenance or have a short lifespan impede the mobility of wheelchair users, and are not cost-effective for clients or third-party payers. Unfortunately, information that compares the quality of power wheelchairs is difficult to obtain. Clinicians often resort to using wheelchair dealers as their primary source of information, but this advice may be biased. Furthermore, clinicians find that it is increasingly difficult to obtain payment authorization for the most appropriate wheelchair for consumers, because objective evaluation and comparison of wheelchairs is not available (1).

The American National Standards Institute (ANSI), RESNA, and International Standards Organization (ISO) have developed standards for qualitative comparison of wheelchairs (2). These standards are a set of procedures that outline how to test and measure various qualities of wheelchairs. Section 8 of the ANSI/RESNA standards requires the use of a double-drum machine, designed to simulate wheelchairs driving over rough terrain, and a curb-drop machine, that simulates traversing down curbs (3).

Previous researchers have used Section 8 of the ANSI/RESNA standards to compare durability and value on manual wheelchairs (1,4,5). Fitzgerald et al. tested 25 depot, 14 lightweight, and 22 ultralight manual wheelchairs until no longer operable, and found ultralight wheelchairs to be significantly more durable ($p<.05$) than lightweight and depot wheelchairs (4). Further analysis by Cooper et al. showed that rehabilitation wheelchairs were significantly more cost-effective ($p<.05$) than depot wheelchairs, with rehabilitation wheelchairs having a value 3.4 times higher than rehabilitation wheelchairs (5). In addition, ultralight wheelchairs were significantly more cost-effective ($p<.05$) than lightweight wheelchairs, with ultralight wheelchairs having a value 3.2 times more than lightweight wheelchairs (1). Currently no known study has tested power wheelchairs until failure in order to compare durability and value.

## RESEARCH QUESTION

Are there differences in the durability and value of powered wheelchairs, from five different manufacturers, when tested according to Section 8 of the ANSI/RESNA standards?

## METHODS

Three identical wheelchairs from five different manufacturers (n=15) were purchased without the knowledge of the manufacturers, which includes the: Pride Healthcare Jazzy 1100 ($4,325), Sunrise Medical Quickie P200 ($5,345), Everest & Jennings Lancer 2000 ($5,437), Invacare Action Arrow Storm ($7,109), and Permobil Chairman ($13,441). Double-drum and curb-drop tests were conducted in accordance to Section 8 of the ANSI/RESNA standards (2). The double-drum machine consists of two drums with four 12-mm slats attached, with the rear drum turning at 1 m/s and the front drum turning 7% faster to ensure that the slats hit against the wheels and casters at different rates. The wheelchairs were loaded with a 100-kg (220-lb.) test dummy and secured to the double-drum machine. The wheelchairs were then placed on the curb-drop machine, which repetitively drops the wheelchairs from a height of 5-cm (2-in.) (Fig 1). The wheelchairs were tested on the double-drum machine for 200,000 cycles and the curb-drop machine for 6,666 cycles, which combined approximates 3-5 years of typical wheelchair use (5), the minimum amount required by ISO for successful passing. In order to determine durability, the wheelchairs were then alternated between the two machines until there was permanent damage, deformation, or failure that affects normal function (Class 3 failure). Durability (number of equivalent cycles) and value (number of equivalent cycles/ retail price of wheelchair) were calculated, based on the following formula used in previous research (1,4,5,7): Equivalent Cycles = (Double-Drum Cycles) + 30 • (Curb-Drop Cycles).

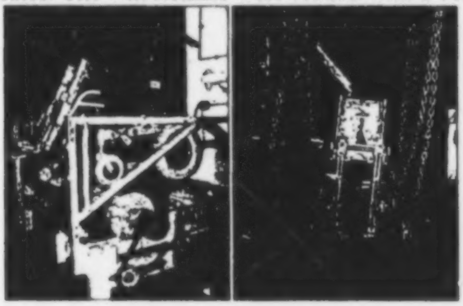

*Fig 1: Double-drum and curb-drop machines*

Testing of the Everest & Jennings and Invacare wheelchairs are still underway and were not included in this statistical analysis. Kruskal-Wallis tests were performed for the nine wheelchairs, with a significance value of 0.05.

## RESULTS

No significant differences (p=.061) in the number of equivalent cycles between the three brands was found (Fig 2). The Pride wheelchairs completed 1,210,892 mean equivalent cycles, the Sunrise wheelchairs completed 425,442 mean equivalent cycles, and the Permobil wheelchairs completed 363,967 mean equivalent cycles. Significant differences (p=.027) in the value between the three brands were found (Fig 3), with the Pride, Sunrise, and Permobil wheelchairs having a mean value of 280, 80, and 27 cycles per dollar, respectively. Table 1 illustrates the number of equivalent cycles completed and describes the failures that occurred.

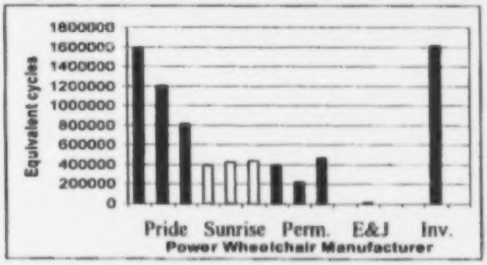

*Fig 2: Durability of Five Wheelchair Manufacturers*

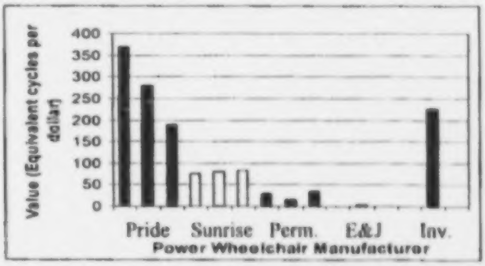

*Fig 3: Value of Five Wheelchair Manufacturers*

## DISCUSSION

Although testing using ANSI/RESNA and ISO standards is optional, the Veteran's Health Administration, the largest purchaser of wheelchairs in the United States, uses these results for purchasing guidance (3). This has lead to the majority of manufacturers opting to test their wheelchairs. In order to comply with the standards, wheelchair manufacturers must present testing results in their product literature, but most manufacturers only make results available upon request. From the perspective of manufacturers, presenting results may cause unfair scrutiny by third-party payers or lawyers, and manufacturers may fear being outdone by competitors (7).

*Table 1: Description of type of failure*

| Model | HCPCS* | Equiv. Cycles | Failure Type |
|---|---|---|---|
| Pride 1 | K0011 | 1,599,920 | Electrical connector |
| Pride 2 | K0011 | 1,209,465 | Right motor |
| Pride 3 | K0011 | 823,292 | Right motor |
| Sunrise 1 | K0011 | 403,358 | Controller |
| Sunrise 2 | K0011 | 432,396 | Controller |
| Sunrise3 | K0011 | 440,573 | Controller |
| E & J 1 | K0014 | 23,712 | Left motor |
| Invacare 3 | K0014 | 1,617,870 | Controller |
| Permobil 1 | K0014 | 399,980 | Electrical connector |
| Permobil 2 | K0014 | 224,330 | Electrical connector |
| Permobil 3 | K0014 | 467,590 | Seat actuator |

*Used for reimbursement purposes (6)

Furthermore, passing the ISO standards only requires that manufacturers test their wheelchairs for a minimum requirement of double-drum and curb-drop cycles, and most power wheelchairs that are tested pass. Testing wheelchairs until no longer operable provides valuable information about types of failures, durability, and value. Results show statistical differences in value for the three different wheelchair manufacturers. Results show no statistical differences in durability, possibly due to the small number of wheelchairs tested. While clinicians should not base their recommendations solely on durability and value information, the results of these tests can provide useful information in helping consumers select appropriate wheelchairs.

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# DESIGN DEVELOPMENT OF A NEW FOLDING COMMODE-SHOWER WHEELCHAIR

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## ABSTRACT

The purpose of this project was to design a new folding commode – shower wheelchair for use by individuals with spinal cord dysfunctions (SCD) and caregivers. The need for this wheelchair resulted from the many safety problems associated with existing models such as inability to fold, patient falls while transferring, development of pressure ulcers and cuts from the seats, etc. An iterative process of design, prototype fabrication and clinical evaluation was used to develop the new wheelchair. The new wheelchair was successfully evaluated with patients with SCD and their caregivers at VA Medical Centers. The evaluation results led to the conclusion that the new folding commode - shower wheelchair solved all the safety and usability problems found in existing models.

## BACKGROUND

There are over 220,000 individuals with spinal cord dysfunctions (SCD) in the United States. The majority of them need to use a commode-shower wheelchair for toileting. Prior to begin this study clinical evaluation of existing commode-shower wheelchairs was conducted and revealed numerous safety-related problems.

## DESIGN DEVELOPMENT

An iterative process of prototype development and clinical evaluation was used to develop the new folding commode - shower wheelchair based upon the following safety & performance criteria:

- *Overall chair safety:* must not contribute to the development of pressure ulcers, nor cause injuries to patients due to falls while transferring or bending forward to wash the feet.
- *Wheelchair positioning over a toilet:* must fit properly over a toilet bowl to prevent fecal matter from falling on the floor.
- *Seat:* must be designed for under seat hand access from 3 sides, be waterproof, provide full thigh support and be cushioned to avoid skin pressure.
- *Seating position:* must be sloped 5 degrees toward the back to hold the user safely in place.
- *Armrests:* must swing out of the way for transfers, provide a resting-place for the forearms, support the user's body weight while hooking under them, or lifting themselves.
- *Caregiver friendly:* must provide for unrestricted hand access to the perianal area of the patient. The footrests must adjust easily for users of varying height.
- *Propulsion pushrims:* must have appropriately sized pushrims for optimum hand positioning and grip and be coated with non-slippery material to assist propulsion in wet environments.

*Development process*

1. Body Support

Seat design: A new rectangular seat was designed allowing under seat hand access in three positions (front, left and right side) and incorporating front "wings" projecting on the sides to facilitate side transfers.

Seat cushioning: Various foam densities were evaluated with a pressure-mapping system. The results indicated that low-pressure readings were dependent not only on the amount of padding but also with the use of a softer density of foam under the ischial tuberosoties versus a harder density foam for the rest of the seat.

Armrests: Lockable pivoting and swing away armrests, capable of holding patients weighing upward of 100 kg were designed. In the locked position, users can latch under them and pull up without fear of unlocking. A lever release mechanism was developed to lock and unlock the armrests.

Footrests: A deep heel-cup contoured footrest to fit the bottom of the foot was designed. To avoid potential ankle injuries, all edges are rounded and smooth. A hole is included for water drainage.

2. Driving wheels/pushrims

Wheels of 55 cm in diameter, instead of the customary 61cm wheels were selected, as the smaller wheels enable to better center over the toilet bowl. Previously developped and patented 3.5 cm diameter rubber coated pushrims were used for their enhanced grasping ability.

3. Folding mechanism

The folding mechanism consists of two sets of identical double leaf hinges. The first hinge is mounted vertically on the front of the chair while the other is mounted horizontally under the seat. The under seat hinge has one of its two leaves attached to one half of the seat. Folding the wheelchair is acheived by lifting the unattached seat portion and pulling upward.

## EVALUATION

Folding wheelchair prototypes were clinically evaluated with thirty patients and caregivers at two VA Medical Centers. Evaluation involved group discussions, actual use of the wheelchairs and questionnaire assesment of the wheelchair's features and usage by patients and caregivers.

## DISCUSSION

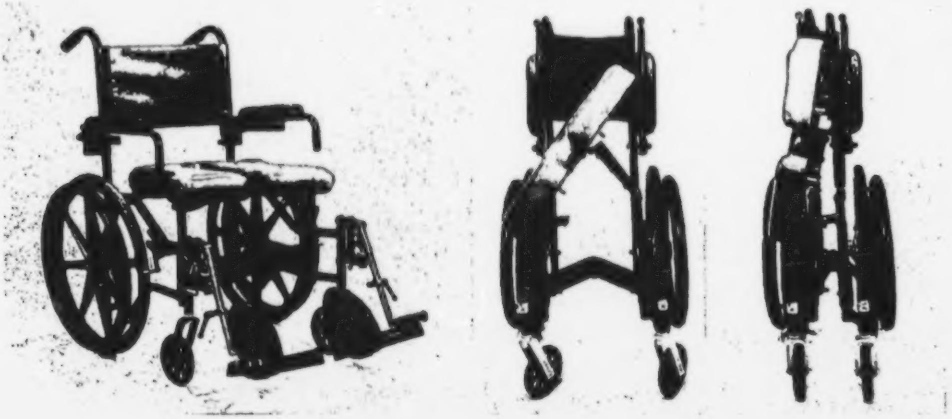
Overall comments: The new folding commode-shower wheelchair was found to fit conveniently in shower stalls and over toilets and to improve showering and toileting via the many places available for patients to grasp and hold.

Stability: Both patients and caregivers found the wheelchair to be stable while in use or for transferring. The brakes were found to be easily activated and effective in holding the wheelchair.

Seating comfort: Both patients and caregivers found that the seat was comfortable and that they were able to reach under it easily. The seat opening was found to be of adequate size and that the seat cover material was not slippery when wet.

Armrests: Both patients and caregivers found that they were strong, that the pads were comfortable and the lever release mechanism easy to use.

Footrests: Both patients and caregivers found that they held the feet properly and safely in place, and to be easily adjustable by caregivers.
Pushrims: The pushrims received positive responses for their larger size and gripping effectiveness when wet.



## ACKNOWLEDGMENTS

This study was funded by the Rehabilitation R&D Service, US Department of Veterans Affairs, Washington DC. The team collaborated with Everest & Jennings (E&J) for developing the Folding commode-shower wheelchair. At the completion of the project, the DVA decided to patent the many new features of the wheelchair and to license manufacturing and marketing to E&J.

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# USING TELERHABILITATION TO AID IN SELECTING A WHEELCHAIR

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## ABSTRACT

Telerehabilitation shows the promise to be able to improve access to seating and mobility specialists for people living in rural and remote areas. An experimental crossover study design was used to establish a scientific basis for the reliable use and limits of telerehabilitation (TR) during mobility assessments. A specific goal addressed in this study was to compare the type of wheelchair the person actually uses to the wheelchair recommended via telerehabilitation (TR) and in-person (IP) assessments. The Kappa measure for agreement for wheelchair recommendations via TR was at .760, for wheelchair recommendation via IP was at .749, and for wheelchair recommendation of IP vs. TR was at .915. Theses results indicate promise for telerehabilitation to be a useful tool in wheelchair recommendations.

## INTRODUCTION

Many different medical disciplines have tested the feasibility and success of telemedicine in their practices. It is possible to apply the same technology learned in other telemedicine disciplines to the field of rehabilitation (1)(2). Telerehabilitation uses videoconferencing and data acquisition technologies. Telerehabilitation can be used in educational situations between clinicians and rehabilitation experts. It can also be used in rural settings where the delivery of rehabilitation and assistive technology (AT) is problematic. The problems of providing AT in rural areas parallel the delivery of health care to rural and remote areas where the proportion of people with chronic illnesses is higher and the means to pay for them is reduced (3). Large distances mean long travel times, increasing costs associated with any service delivery and consuming valuable time that specialized professionals could be using to provide services. Therefore, individuals living in rural areas that are in need of mobility devices face two major problems: the shortage of specialists in mobility assessment; and the lack of accessibility to specialists for those living in rural areas.

## RESEARCH QUESTION

When conducting a mobility evaluation what is the level of agreement in the recommendations of the type of wheelchair a person actually uses when assessed via telerehabilitation (TR) and assessed via in person (IP)? Secondary what level of agreement exists among therapist when conducting the assessments via TR and via IP?

## METHODS

Four licensed therapists with experience in seating and mobility evaluations conducted assessments, on 20 model patients, at the UPMC Center for Assistive Technology (CAT) located in Forbes Tower and the Human Engineering Research Laboratories (HERL) located at the Highland Drive VA. The group of model patients consisted ten females and ten males with the mean age of 42.4 years with a standard deviation of ± 13.1 years. The primary diagnoses included degenerative Arthritis, Engelman disease, Cerebral Palsy, Spinal Cord Injury, Head Injury, Spinal Muscular Atrophy, Severe Osteoporosis, Spina Bifida, Diabetes, Muscular Dystrophy and Multiple Sclerosis. The model patients used a standard wheelchair during the assessment in order to avoid biasing the evaluators towards a prescription. The evaluation protocol used by the clinicians consisted of an interview, to establish the need, the appropriateness and the goal for assistive technology intervention; and a mat evaluation for baseline information on physical/mobility information. Each clinician evaluated each of the 20 model patients one time only either by TR or by face-to-face. The TR assessment was conducted with an "assistant " at either HERL or CAT under the supervision of one of the four study therapists observing from a remote location at the CAT or HERL. As part of this process a clinical assessment form and evaluation check list were used to record information on the individual and their mobility status. Examinations rooms were equipped with optimal lighting, a modular analogue phone connection and means for assuring privacy for the model patient. Video conferencing equipment ( PolyCom Sound Station) used was based on a standard phone line (POTS [Plain old telephone system]) and the video images were viewed on a Panasonic 21" x 16" TV screen. For the statistical analysis the kappa statistic determined the level of agreement. A kappa value of >.75 was interpreted as excellent agreement (4).

## RESULTS

The results are summarized in tables 1, 2 & 3 below. Telerehabilitation was done at two different locations. But since there was high correlation between the two sites, only one site (CAT) is shown in the results.

**Table 1: Wheelchair Recommendation via Telerehabiltation (TR)**

| Subjects current wheelchair | TR at CAT Manual | TR at CAT Power | TR at CAT Scooter | Total |
|---|---|---|---|---|
| Manual | **5** | 1 | 1 | 7 |
| Power | | **9** | 1 | 10 |
| Scooter | | | **3** | 3 |
| Total | 5 | 10 | 5 | 20 |

**Kappa measure for agreement: .760**

**Table 2: Wheelchair Recommendation In Person ( IP)**

| Subjects current wheelchair | IP at CAT Manual | IP at CAT Power | IP at CAT Scooter | Total |
|---|---|---|---|---|
| Manual | **6** | 1 | | 7 |
| Power | | **9** | 1 | 10 |
| Scooter | | 1 | **2** | 3 |
| Total | 6 | 11 | 3 | 20 |

**Kappa measure for agreement: .749**

**Table 3: Wheelchair Recommendation of in-person (IP) vs. telerehab. (TR)**

| IP at CAT | TR at CAT Manual | TR at CAT Power | TR at Scooter | Total |
|---|---|---|---|---|
| Manual | **6** | | | 6 |
| Power | | **9** | 1 | 10 |
| Scooter | | | **3** | 3 |
| Total | 6 | 9 | 4 | 19 |

**Kappa measure for agreement: .915**

## DISCUSSION

The results of this study indicate promise for telerehabilitation as a useful tool in wheelchair recommendations.

Therapist utilizing TR demonstrated at high level of agreement in recommending the same basic type of wheelchair that subjects already owned. The analysis of TR assessments vs. IP assessments demonstrated a high level of agreement in the consistency of wheelchair recommendation. This study focused on the recommendation of basic mobility devices such as manual and power wheelchairs, and scooters. Future studies need to be designed to investigate the sensitivity of telerehabilitation addressing specialized seating and mobility needs, for example specific cushion selection, specific back support systems, wheel setting for the power base (front, mid-wheel and rear-wheel drive), and three-wheeled or four-wheeled scooter. The study design restricted the therapists to a pre-scripted interview format in order to avoid biasing the therapists towards a prescription, and therefore information of current mobility history was withheld from the therapist.

Close evaluation, analysis, and possible modification of our current TR intake and documentation forms is indicated to test the usefulness of TR beyond the basic wheelchair recommendation.

## ACKNOWLEDGEMENT

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# VISCOELASTIC PROPERTIES
# OF BUTTOCK SOFT TISSUES WITH PRESSURE ULCER SUSCEPTIBILITY

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## ABSTRACT

Preliminary experiments were performed on the intact buttock soft tissues of 5 subjects with spinal cord injuries (SCI) and histories of pressure ulcers (PU). Compared to the experimental data from 6 subjects withoutSCI, significant differences in the material properties, reduced relaxation parameter, $\alpha$, ($P<0.05$) and elastic response, $E_0$, ($P<0.001$) across the two groups were observed. Further investigation in the SCI population between those with and without pressure ulcer histories is recommended.

## BACKGROUND

People with SCI who sit for long periods of time are at high risk of developing pressure ulcers on the buttock soft tissues over the ischial tuberosities (IT). According to a report of the US Regional SCI System, 8.0% of all ulcers in people with SCI occurring during initial hospitalization occurred over an IT. A VA hospital care review in which patients were followed for 4 years post injury found 23-28% of all ulcers occurred over an IT [1, 2].

## RESEARCH QUESTIONS

Our long-term goal is to identify biomechanical properties that relate to risk for pressure ulcer development. This study focuses on the comparison of biomechanical responses of buttock soft tissues between people without SCI and people with SCI and a history of pressure ulcers.

## METHOD

Five male subjects with spinal cord injuries (C4 to T12) and the occurrence of a pressure ulcer history within the past two years were recruited. None of the subjects had had a PU on the test site. Six control subjects without any neuromuscular disease were recruited. Both groups' age range was from 35 to 64 and body fat percentage was less than 30%.

A Computer Automated Seating System (CASS) (11 by 12 sensor array) and related test protocol for in vivo indentation tests was used for data collection [3, 4]. With the subject sitting on the CASS, the response of his buttock tissues 4 cm in front of ischial tuberosity was recorded. The indentation loading cycle consisted of: indentation at 1mm/sec to 20% of initial thickness of bulk tissue, 5 min. hold 5, and recovery. Tissue thickness was tracked using an automated ultrasound tracking technique. The information record included the thickness of tissue layers, force, and tilt angle of the test sensor. Fung's QLV theory was used to assess viscoelastic parameters of buttock soft tissue.

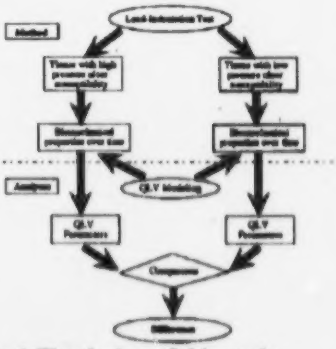


Fig.1 The design of this study

$$P[u(t);t]=G(t)*P^e(u) \qquad G(0)=1 \qquad (1)$$

Where, G(t) is reduced relaxation function that describes the stress response with time, and $P^e(u)$ is the elastic response function.

The Zheng' equations [5] were used to define G(t) and $P^e(u)$.

$$G(t) = 1 - \alpha + \alpha e^{-t/\tau} \qquad (2)$$

$$P^e(u) = \frac{2ah}{(1-v^2)} \mu k(h,\mu) E^e(\mu) \qquad (3)$$

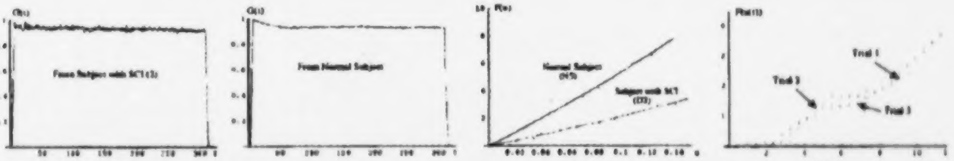
$$E^e(u) = E_0 + E_1 \mu(t) \qquad (4)$$

where, $a$ is the radius of the indenter, $h$ is the original thickness of soft tissue, $k$ is a scaling factor that depends on the Poisson's ratio $v$ and the relative aspect ratio $a/h(1-\mu)$, and $\mu$ is relative indentation. $k$ can be obtained from the table in Hayes' paper in 1972. In this study, the poison's ratio is taken to be 0.45 [3] and the boundary condition was assumed as $G(\infty)=G(300s)$.

The reduced relaxation parameters, $\alpha$, and the time constant, $\tau$, were determined by curve fitting G(t) to experimental data of buttock soft tissue. The unrelaxed initial elastic indentation, $E_0$, and the unrelaxed nonlinear elastic modulus, $E_1$ were determined from the elastic response. Differences of in viscoelastic parameters between the subjects without SCI and the subjects with pressure ulcer SCI was investigated.

## RESULTS

Compared to the results of subjects without SCI, the G(t) curve from subjects with SCI showed much less relaxation. And, the relaxation for the SCI group tended to be linear (Fig.2 (a)). The data from subjects without SCI showed clear reduced relaxation and fast viscous phenomenon (Fig.2 (b)). The comparison of two typical elastic response curves between the groups is displayed in Fig. 2 (c). A decreased amplitude of stress, $P^e(\mu)$, for the SCI subject was observed. A non-linear elastic response phenomenon in a set of data from an SCI subject



(a) (b) (c) (d)

Fig. 2 (a) A typical G(t) Curve from subject with SCI and pressure ulcer history; (b) A typical G(t) Curve from subject without paraplegia; (c) Comparison of elastic response data across two research groups. (d) A set of typical elastic response from disabled subject 3

Table 1 Comparison of QLV parameters between two groups

| Parameter Range | Results from subjects without paraplegia | | | | Results from subjects with pressure ulcer susceptibility | | | |
|---|---|---|---|---|---|---|---|---|
| | α | τ (s) | $E_0$ (N/mm$^2$) | $E_1$ (N/mm$^2$) | α | τ (s) | $E_0$ (N/mm$^2$) | $E_1$ (N/mm$^2$) |
| Mean | 0.068-0.328 | 44.2 – 164.2 | 18 – 42 | -93- +46 | 0.016-0.130 | 25.3 –81.2 | -11.2 – +9.63 | -18.5 - +395 |
| Standard Deviation | <0.039 | <54.5 | < 10 | < 65 | <0.104 | <38.3 | <7.5 | < 41 |
| Mean Square Error for curve fitting | <5% | | | | <11% | | | |

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was also observed (Fig. 2 (d). This particular elastic response curve took a 4th order non-linear shape. The comparison of QLV parameters is summarized in Table 1. Significant differences exist for $\alpha$ ($P<0.05$) and for $E_0$ ($P < 0.001$) between the two groups.

## DISCUSSION

The CASS, data acquisition protocol, and QLV modeling have been successfully used to analyze the difference in viscoelastic properties of buttock soft tissues between subjects with SCI and a history of having had a pressure ulcer and subjects without SCI. A future investigation should be conducted to compare the visoelastic properties of subjects with SCI with and without histories of having had a pressure ulcer.

In addition, for most subjects, the elastic response modulus was linear. However, a higher order (nonlinear) elastic response was observed in one subject in the SCI group. A higher body fat percentage and greater fat tissue thickness may explain the difference in the elastic response in this particular subject compared to the others. The physical interpretation of this high-order QLV model parameter should be further studied and given definition.

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# A SURVEY OF ALTERNATING PRESSURE SEAT CUSHIONS

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## ABSTRACT

A survey was conducted to determine the characteristics of alternating pressure seat cushions commercially available in the United States. This survey was completed in preparation for subsequent research regarding the physiological effects of alternating pressure on buttocks tissue.

## BACKGROUND

The benefits of alternating pressure were recognized as early as 1961, when alternating and constant pressure on both normal and denervated tissue in rat hamstrings were analyzed (1). The study showed that tissue damage from alternating pressure is less severe when compared to constant pressure. A 1976 study of five normal adults seated on a contoured, dynamic surface suggested that alternating pressure-seating surfaces provide improved pressure distributing characteristics. (2). The cushions developed as a result of information in the literature vary widely in design criteria ratings suggesting further research in this area.

## RESEARCH QUESTIONS

The need to study the efficacy, and eventually the effectiveness, of alternating pressure cushions in preventing pressure ulcers exists. In order to determine cushion efficacy, critical characteristics need to be defined, hypotheses about clinically relevant characteristics drawn, and the effect of such characteristics on cushion performance determined.

## METHOD

This study surveyed the alternating pressure cushions commercially available in the United States to determine the distinguishing characteristics. Information was obtained through a literature search, an internet search to locate manufacturers, telephone calls to the manufacturers, and consumer pamphlets. Cushions were included only if manufacturers provided relevant information.

## RESULTS

Eleven cushions from eight manufacturers were identified with information concerning cycle time, the geometry and pattern of the cells, the cushion and cover composition, and fail safety mechanism. These characteristics vary greatly among the cushions identified in the table.

The cycle time of the cushion is the time to complete one full cycle of inflation and deflation. Pressure relief is provided by the cyclic high and low pressure or the change from being inflated to deflated. The cycle time may affect active and reactive hyperemia, blood flow, occlusion, lymphatic flow, and recovery rate. The various manufacturers have developed cushions with a wide range of cycle times (36 sec - 20 min). This broad range is indicative of the lack of evidence regarding the effects of the various cycle times.

The geometry of the cells within the cushion may be critical to the performance of the cushion; e.g. increased cell height prevents "bottoming out" but may compromise stability. The height dimensions obtained range from 1.375 to 5 inches, causing concern for either situation. The potential for instability of the Pegasus Airwave (5") is compensated for by the fact that the cushion does not sit at the level of the standard sling seat. The cushion comes with attachments that allow it to be recessed below this level, lowering the cushion height to approximately 2.5 inches. Some cushions have variable height, e.g. Aquila Corp's Airpulse PK cushion, to promote immersion.

The length and width of the cells vary with the pattern of the cushion, cells are typically 2 to 3 inches by the width of the cushion as is the case with 7 of the 11 cushions. The exceptions are the Equalizer (Dynamic Air, Inc.)and the Airwave (Pegasus) that incorporate foam into the cushion design and both cushions developed by Aquila Corp, Airpulse and Airpulse PK. The Aquila cushions utilize many small air cells to achieve the alternating pressure. The Airpulse has cells of uniform dimension and the Airpulse PK uses non-uniform, symmetrical cells. An advantage to using numerous, small air cells is that there is greater potential for airflow underneath the user from the space between the cells. This is advantageous for both moisture and temperature control. Another benefit to the Aquila Corp cushions is the ability to offload the ischial tuberosities. The base of the Equalizer is composed of air cells surrounded by foam giving both static and dynamic qualities. The four air cells within the Airwave cushion are unique in that they run front to back and are among the largest.

Cushion cover materials influence the health of nearby tissue (microenvironment). Skin is more prone to injury in the presence of moisture (3, 4) making it vital that the materials of the cover allow for a significant moisture vapor transmission rate to counteract the moisture from perspiration, urine, and feces. Thus circulation of air between the cushion and user is important in preventing pressure ulcers (3, 4). Of the eleven cushions surveyed, three came with Dartex (polyurethane) covers, two with a jersey fabric, two with a cotton/polyester blend, one was polyurethane coated nylon, two of nylon, and three unknown. Some cushions come with the choice of more than one cover. The most frequent cover material is polyurethane because of its many advantageous characteristics: stretch, moisture resistance, and vapor permeability as well as being anti-microbial, anti-allergenic, anti-static, fireproof, and can be heat welded (5). The jersey fabric and the cotton/polyester blend provide stretch and high vapor permeability with the cotton/polyester blend adding moisture resistance. Cochran used a jersey material in a pilot study of evaluating wheelchair cushions if no cover was provided (6).

The cushion materials include four made of PVC, three composed of urethane, two of latex with optional neoprene, and two of unknown composition. There are more materials listed than cushions surveyed because some of the cushions are composed of multiple materials.

Each cushion should have some form of fail safety to alert the user to such hazards as a low battery or low air pressure. Krouskop (4) supports this view. Six of the eight manufacturers provided information regarding the method to which the user is alerted to a system failure. The alerts are audible, visual, or both. The Huntleigh Aura has both low pressure and power fail alarms. In the event that either occurs, a red alarm indicator will flash and an alarm will sound that has an increasing pitch with time. Other cushions, such as The Sentech Air Chair have sensor-controlled alerts for low battery.

Conclusions are difficult to draw at the present time as to the most effective cycle time or geometry and pattern of air cells because of the lack of data. Hopefully this paucity can be overcome to aid in future design, standards development, and consumer selection. Here, some of the design characteristics are presented to show the vast variation between manufacturers.

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| | | Cell dimensions | | | | Materials | | |
|---|---|---|---|---|---|---|---|---|
| Company Cushion | Cycle time (min) | Length x width (inches) | Height (inches) | Number of cells | Cell layout | Cushion | Cover | Fail Safety |
| Aquila Corp Airpulse | Variable | 2" diameter | 3 | Variable[2] | Rows – right to left | Latex (optional neoprene coating) | Cotton/polyester blend w/ or w/o cotton | Audible |
| Aquila Corp Airpulse PK | 10 preset conditions | Variable | Min: 3<br>Max: 4 | Variable[2] | | Latex (optional neoprene coating) | Cotton/polyester blend w/ or w/o cotton | Audible |
| BlueChip Medical Chair Air 9700c | 5 | 3.25 x 18 | 3.25 | 6 | Rows – right to left | | Vapor permeable nylon | |
| Dynamic Air, Inc. Equalizer | 30 | 1.5 diameter | | 48 | Rows | Foam and polyurethane | Dartex | Audible and Visual |
| E.A.S.E.[1] Active Massage Wheelchair Cushion | 12 | 1.375 x width of cushion | 1.375 | Variable[2] | Rows – right to left | Urethane foam base | Flexible nylon | Alarm |
| Grant Airmass Model DQZ | 4 | 2 x width of cushion | 1.5 | 12 | Rows – right to left | PVC[3] | | |
| Grant Airmass Model KBQZ | 4 | 2 x width of cushion | 1.5 | 12 | Rows – right to left | PVC[3] | | |
| Grant Airmass Model KQZ | 4 | 2 x width of cushion | 1.5 | 12 | Rows – right to left | PVC[3] | | |
| Huntleigh Aura | 10 | x width of cushion | Min: 2 | 9 | Rows – right to left | PVC w/ plasticizer | Dartex | Audible and visual |
| Pegasus Airwave | 12 | 3 x 14 | 5 | 4 | Rows – front to back | | Dartex | Audible and visual |
| Sentech Air Chair | 2.5 | 2.5 x 18 | 2.5 | 10 | Rows – right to left | Polyurethane coated nylon | Polyurethane coated nylon | sensor |

[1] Eagle Advanced Systems Engineering
[2] Dependent on size of cushion
[3] Polyvinyl chloride

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# WHEELCHAIR BRAKING BIOMECHANICS

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## ABSTRACT

Wheelchair propulsion biomechanical research investigates how wheelchair users apply forces to the pushrim, and also to learn how to reduce the level of forces across joint structures. This study expanded the scope of previous investigations by examining starting and braking of a wheelchair. Nine subjects were tested using a SMART$^{Wheel}$ system. The results showed that abrupt braking required approximately 160% more peak tangential force, Ft, than starting and about 230% more than constant propulsion (1.8 m/s). The maximum rate of rise of Ft in braking was about 260% larger than in starting. Given these results, wheelchair users may want to avoid abrupt starting and braking when possible. And researcher may want to investigate these conditions in relation to injury

## BACKGROUND

One reason for studying biomechanics of wheelchair propulsion is to gain understanding of upper limb pain and injury, which is common among manual wheelchair users (1), (2). Upper limb pain can limit strength and reduce mobility, thus leading to a loss of independence. When a wheelchair is propelled either forward or backward, the forces transferred to the pushrim are equally and oppositely delivered back to the manual wheelchair user's upper limb. Pushrim forces and moments occurring during wheelchair propulsion at a constant speed have been studied (1) to gain insight into the cause of upper limb pain. However, in a real environmental situation, the manual wheelchair users do not always push the wheelchair at a constant speed. Acceleration and deceleration of the wheelchair are also necessary. Manual wheelchair users may need to suddenly start or brake. Propelling a wheelchair quickly or braking a wheelchair suddenly likely causes different forces and moments to be transmitted to the upper limbs than steady state propulsion. Research relative to wheelchair starting and braking biomechanics has been limited. The objective of this study was to describe the forces and moments occurring during wheelchair propulsion (starting, braking, and constant speed), and to compare these three conditions. The hypothesis of this study was that the overall peak forces and moments and the maximum rate of rise would be greater in starting and braking modalities than in a constant speed modality, and that braking would entail more, and opposite, forces and moments than starting.

## METHODS

Nine subjects with spinal cord injury below a T2 level participated in testing. Kinetic data were obtained using the SMART$^{Wheel}$, a force- and moment-sensing pushrim. The subject's wheelchair was aligned and secured over the rollers of a computer numerically controlled dynamometer. During the test session, subjects propelled their wheelchair on the dynamometer for five minutes to become acclimated. Each subject pushed the wheelchair at 1.8 m/s (4 mph) for two minutes. Data were stored for the last 20 seconds of each test. The subject were allowed a rest period and then were instructed to push the wheelchair as fast as possible from standstill and then stop the wheelchair as quickly as possible, while data were collected. Pushrim force and hub moment data were stored at 240 Hz and low-pass filtered at 30 Hz. The SMART$^{Wheel}$ returns three components of forces (Fx, Fy, and Fz) and of moments (Mx, My, and Mz). The force radial to the pushrim, Fr, and a force tangential to the pushrim, Ft, were calculated using mathematical transformation (3). The peak forces and moments as well as the maximum rate of rise of the forces and moments were determined for the following: Fr, Ft, Fz, Mx, and My. These parameters were chosen because they represented values relating to injury mechanisms (1). Since Mz is approximately equal to Ft multiplied by the radius of pushrim, Mz was not analyzed. This study compared the data on peak forces and moments (Ft, Fr, Fz, Mx, and My), maximum rate of rise of the forces and moments among three different situations; wheelchair constant speed (1.8 m/s), quick wheelchair starting, and wheelchair braking. Data on peak forces and moments were obtained from the first stroke of starting and the stroke occurring in braking. For the constant condition, the first three strokes were averaged. All parameters were computed using Matlab (MathWorks, Natick, MA). Statistical analysis was performed using StatView (SAS Institute Inc., Cary, NC). Post hoc multiple comparison (repeated measures) was conducted to look for the significant differences among the three modalities (starting, braking, and constant speed). A p value of less than 0.05 was considered statistically significant.

## RESULTS

Figure 1 shows the results of this study. Each bar in the plots represents the average values with standard deviation shown as a vertical line. The horizontal arrows were drawn only when there were significant differences ($p < 0.05$) between the two situations. As can be seen in the figure 1-(a) and (b), there were significant differences in Ft among constant, starting, and braking conditions. When a user quickly started pushing the pushrim, the Ft exceeded the force needed for constant speed propulsion by approximately 144%. Abrupt braking entailed more but opposite tangential force that was about 159% more than starting. There were no statistical differences in Fr whereas Fz decreased with braking by 60% of that of starting and 73% of that of constant velocity. As shown in the figure 1-(c) and (d), the maximum rate of rise of forces and moments increased with braking. The abrupt braking caused the maximum rate of rise in Ft to be approximately 230% larger. The twisting moments exerted by the hand on the pushrim, Mx and My, were increased by 216% and 261% of starting and constant conditions respectively.

## DISCUSSION

In this study, abrupt braking of a wheelchair required the largest peak forces in Ft and Fr. In addition, the maximum rate of rise of Ft, and Mx were the highest with braking. The next largest forces in Ft and Fr, and the next largest moments occurred during quick starting. Thus, the task of quick wheelchair starting and braking required large forces and rapid changes. This force generation may play a role in causing upper limb injury because the magnitude of forces seen at the pushrim will be reflected in joint reaction forces. The decrease in Fz with braking is understandable because, in deceleration condition, the tangential friction is mainly generated by hand grabbing the pushrim. Whereas, in acceleration condition, the radial and z-directional forces apply to generate friction between the hand and the pushrim. The reason that the maximum rates of rise in starting is less

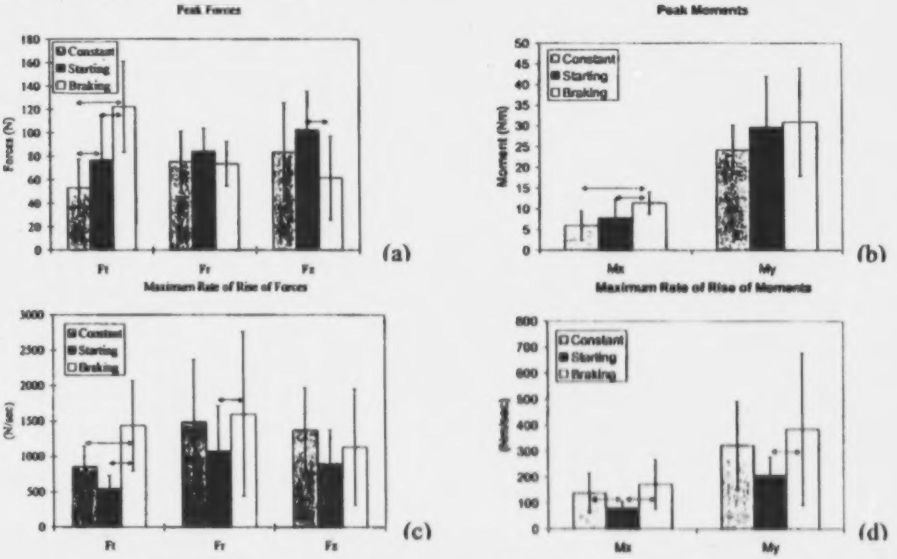

Figure 1. These plots represent the data on peak forces and moments, maximum rate of rise of the forces and moments; (a) peaks of tangential force, Ft, radial force, Fr, and z-directional force, Fz, (b) peaks of x and y-directional moments, (c) maximum rate of rise in Ft, Fr, and Fz, (d) maximum rate of rise in Mx and My.

even than in constant situation likely lies in the fact that subjects were working to overcome inertia. Therefore, when users started to push the pushrim, they gradually increased the pushing force even though they were asked to start as quickly as possible.

It may be possible to reduce the magnitude of these potentially injurious parameters through modification of the braking method. Educating individuals to avoid rapid acceleration and rapid deceleration when possible is a good first step. Given these results, investigators should consider starting and braking condition when studying wheelchair propulsion. Wheelchair users usually do not start or brake their wheelchairs abruptly. However, even small acceleration or deceleration of their wheelchairs likely require larger forces and moments. Further investigation into the less abrupt wheelchair starting and braking may provide additional valuable information.

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# GENDER DIFFERENCE IN THE SEGMENTAL POWER AND ENERGY OF MANUAL WHEELCHAIR PROPULSION

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## Abstract

The purpose of this paper was to expand our understanding of the gender difference in segmental power and energy of manual wheelchair propulsion (MWP). Ten male and eight female subjects participated in the recording of three-dimensional motion of their upper limbs during MWP. Segmental energy and power were computed for each subject. A statistical analysis using an unpaired t-test indicated that females had significantly higher maximum and minimum power, mean and maximum energy for all segments. The tendency towards higher power and energy transfer implies that women were weaker than the men in terms of physical performance capacity.

## Background

Investigation of gender difference in wheelchair propulsion may provide insight into physical performance capabilities and injury prevention. Power output and total mechanical energy transfer are assumed to be indicators for physical performance capacity [1]. The patterns of energy transfer and power of the individual segment of the upper extremity have been previously studied [2], but no research appears to have considered differences between men and women. Previous studies have demonstrated gender difference in the anthropometric [3] and kinematic [4] features of manual wheelchair propulsion (MWP). Dicianno *et al.* showed that women pushed their wheelchairs with higher weight normalized forces than men given a specific speed [5]. Furthermore, a magnetic resonance imaging analysis revealed that women who use manual wheelchairs may also be at a higher risk for developing upper extremity injuries than men [5]. For this reason it is important to obtain further information regarding the kinetic characteristics between men and women.

Thus, it is the purpose of this study to investigate gender differences in segmental power and energy of manual wheelchair propulsion.

## Methods

*Subjects.* Eighteen manual wheelchair users with spinal cord injuries at the T2 level or below gave informed consent to participate in this study. The sample consisted of 10 men and 8 women. The subject information is listed in Table 1.

**Table1 Subject Information**

| | Age (yr) | Post Injury (yr) | Body Weight (N) |
|---|---|---|---|
| Male | 33.37(7.65) | 10.92(5.85) | 179.6(26.9) |
| Female | 36.98(8.32) | 12.78(4.95) | 137.3(47.4) |

*Test Protocol.* Subjects were tested in their own wheelchairs which were secured to a wheelchair dynamometer. Subjects were centered between two three-dimensional camera systems (OPTOTRAK, Northern Digital Inc.). IRED (Infrared emitting diode) markers were placed on the subject's acromion process, lateral epicondyle, ulnar styloid, third metacarpophalangeal (MP) joint and the wheelchair hub. Each subject was asked to push his/her own wheelchair and keep the velocity at a constant level of 0.9m/s (2mph). After reaching steady state, the kinematic data were recorded at a sampling rate of 60 Hz for 20 seconds.

*Calculation of Segmental Energy Transfer.* The work-energy theorem enables two methods to calculate the net power supplied to the segment. One is to add up the segment's muscle and joint powers. The other is to calculate the power by taking the time derivative of the segment's total mechanical energy. The later one may be more accurate since the measures depend only upon kinematic and anthropometric data [6].

In this study, the segment's total mechanical energy was calculated by adding the potential energy and the kinetic energy of this segment together:

$$E(s,t_1) = m(s)\cdot g\cdot Y(s,t_1) + \tfrac{1}{2}\cdot m(s)\cdot [V(s,t_1)]^2 + \tfrac{1}{2}\cdot I(s)\cdot [\omega(s,t_1)]^2 \qquad (1)$$

Where $m(s)$ and $I(s)$ are its mass and moment of inertia about a medio-lateral axis through center of gravity. $Y(s,t_1)$ is the height of its center of mass, and $V(s,t_1)$, $\omega(s,t_1)$ are its linear and angular velocity at time $t_1$. The net power was calculated by the finite difference equation as follows:

$$P(s,t_1) = \dot{E}(s,t_1) = [E(s,t_2) - E(s,t_0)]/2\Delta t \qquad (2)$$

Where $t_0$, $t_1$, $t_2$ represent different times separated by the sampling interval of camera system All calculation was implemented in MATLAB (Mathworks Inc.).

For each subject, only one complete propulsion cycle was analyzed. Subjects characteristics and the mean and maximum power and energy were compared between groups using an independent samples t-test.

## Results

An unpaired t-test showed no significant differences in the age (p=0.354) and the post injury years (p=0.485) between males and females. Average body weight was significantly greater for the male group (p=0.029). As a result, the mean and the maximum values of segment energy and power were normalized with respect to the corresponding segment weight. Segment weights were determined by the method proposed by Winter [7].

Female subjects had significantly greater absolute values of maximum and minimum segmental power, mean and maximum segmental energy for all three segments of upper extremity (Tables 2 and 3). Mean segmental power was not included since it is always 0 in periodic motion (the energy generation, absorption and transfer were balanced over one complete cycle).

**Table 2 Segmental energy distribution statistics**

**Female**

| | Mean** | Max** |
|---|---|---|
| Upper arm | 8.223(2.184) | 8.468(2.205) |
| Forearm | 6.533(1.344) | 7.087(1.317) |
| Hand | 6.716(1.040) | 7.559(1.377) |

**Male**

| | Mean** | Max** |
|---|---|---|
| Upper arm | 4.783(1.777) | 4.965(1.831) |
| Forearm | 3.981(1.233) | 4.358(1.331) |
| Hand | 4.063(0.816) | 4.591(0.919) |

**Table 3 Segmental power distribution statistics**

**Female**

| | Min* | Max* |
|---|---|---|
| Upper arm | -2.718(0.849) | 2.738(1.085) |
| Forearm | -6.194(1.858) | 6.453(2.236) |
| Hand | -11.202(5.725) | 8.875(3.814) |

**Male**

| | Min* | Max* |
|---|---|---|
| Upper arm | -1.649(0.581) | 1.607(0.743) |
| Forearm | -3.99 (0.019) | 3.520(2.252) |
| Hand | -5.489(0.139) | 5.224(1.924) |

* indicates significant difference($P<0.05$)
** indicates significant difference($P<0.005$)

## Discussion

Higher maximum and minimum segmental power and higher mean and maximum segmental energy were discovered in the female group. It appears that the female group may have weaker physical performance capacity than the male group, since they require more positive net energy transfer to each segment and higher energy transfer rate to accomplish the comparable output work (all the subjects propelled the wheelchair at the same speed and under the same rolling friction load). The results are reinforced by findings reported by other investigators [8] and they may help explain why female MWU are more likely to experience joint injury and degeneration over time as observed [5].

## Conclusion

The differences suggest that higher power and more energy transfer within segments of upper extremity are required by the women wheelchair users during MWP. These findings may provide guidance into the design and construction of wheelchairs and the development of specified interventions and propulsion techniques for women wheelchair users.

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# COMPARISON OF HYBRID III ATD AND WHEELCHAIR USER AT SELECTED SPEEDS

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## ABSTRACT

Hybrid test dummies provide a safe alternative to human subjects when investigating mechanisms of wheelchair tips and falls. The data researchers acquire from these test dummies is more valid if the test dummy represents the population being studied. The goal of this study was to determine if a modified 50th percentile male Hybrid III anthropomorphic test dummy (HTD) has a similar dynamic response as a wheelchair user with a spinal cord injury. The trunk angular displacement was similar between test cases and correlations indicate that motion of a wheelchair user can be predicted from the response of the HTD. A reliable and accurate test dummy is necessary for legitimate results and ultimately the reduction in accident frequency and severity.

## BACKGROUND

There are approximately 1.5 – 2 million full-time wheelchair users in the United States. An estimated 3.3% per year experience a serious wheelchair-related accident (1). About 70% of these accidents are attributable to tips and falls [(1),(2)]. Despite the increasing trend in wheelchair accidents every year, there is little literature on the cause and prevention of these accidents. Test dummies provide an ethical and practical alternative to subjects when assessing the risks and prevention mechanisms of tips and falls in controlled studies.

Data researchers acquire from these test dummies is more valid if the test dummy represents the population being studied. Dynamic response characteristics of the test dummy must be isolated for comparisons with the sample population it is to represent. When confronted with a system whose dynamics are to be identified, it is important to select what inputs will be manipulated so as to "excite" the system during the experiment (3). This paper combines two input parameters in its investigation: the initial velocity and deceleration of an electric powered wheelchair.

The goal of this study was to determine if a modified 50th percentile male Hybrid III anthropomorphic test dummy has a similar dynamic response as a wheelchair user with a spinal cord injury during low speed, low impact scenarios. A test device with comparable characteristics will enhance understanding of how the user, wheelchair, and environment interact, and may lead to greater mobility and less risk of injury.

## METHODS

*HTD Development:* Modifications were made to a Hybrid III test dummy in order to provide more motion in the hip joints, and therefore, more realistic trunk motion. Changes included the use of a "pedestrian" pelvis with an accompanying straight lumbar spine in place of the seated pelvis with curved lumbar spine. The foam/rubber buttocks were removed and instead low-density polyurethane foam was used to mimic flaccid tissue. The abdomen was removed to reduce trunk resistance and bolts at the joints were loosened and lubricated to decrease lower extremity joint stiffness. These modifications were done to simulate a person with lower extremity paralysis.

*HTD Validation:* A single wheelchair user with T8 paraplegia due to traumatic spinal cord injury was used for comparison. The test dummy was clothed to provide similar friction with the seat as the test pilot. A kinematic analysis of the trunk bending during a braking trial was used to endorse the modifications to the HTD. Active markers were fixed to the shoulder, hip, and knee to capture the trunk motion. The HTD and test pilot were seated in the wheelchair as depicted in **Figure 1** with arms abducted and forearm flexed to prevent using them for support during trials. While the test pilot was seated in the chair, two spotters were positioned approximately 1.5 meters beyond the braking line to intervene in case of falls.

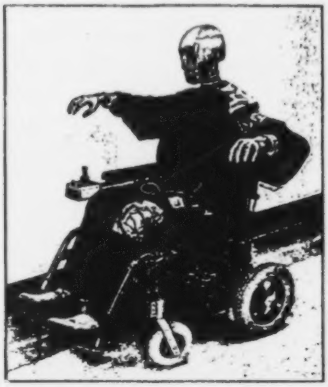
Figure 1 – Hybrid III test dummy seated in P100 test wheelchair

*Test Wheelchair:* The input disturbance was provided by a Quickie P100 (Sunrise Medical, Inc.). The P100 was selected based upon availability at our research center and because it presented minimal risk of causing a fall to the test pilot. Both the HTD and test pilot were seated on a 50mm polyurethane foam cushion. Markers were placed on the front edge of the seat pan and at the intersection of the seat pan and back support for determining wheelchair velocity, acceleration, and orientation.

*Experimental Protocol:* Testing was performed in the EZ-Street located at the Human Engineering Research Laboratories. An OPTO*TRAK* 3020 (Northern Digital, Inc.) motion measurement system was used to sample 3-D position data of the markers at 240 Hz. Data were analyzed using custom programs written in Matlab (The Mathworks, Inc.).

Test protocol included three braking conditions: joystick release, joystick full reverse, and emergency power-off. In addition, the braking conditions were enacted with three power wheelchair initial velocities: slow, medium, and fast. The slowest speed was obtained by turning the potentiometer on the joystick to its minimum value. Likewise, the maximum speed was achieved by turning the potentiometer to its maximum value. The potentiometer was tuned to provide a mid-range speed. One test operator drove the P100 from the right side without obscuring the markers. A 6 meter run-up area was used to achieve the selected speed of the wheelchair. The test operator initiated the braking scenario when the front caster crossed a braking line labeled on the floor. Position data from the joystick, as well as velocity and acceleration curves of the wheelchair were analyzed to pinpoint the exact start of braking.

*Data Reduction:* The trunk angular displacement was calculated using a sagittal plane projection of markers placed on the knee, hip, and shoulder. Angular displacement data were numerically differentiated to obtain trunk angular velocity, and acceleration. The trunk kinematics were used as measures of comparison between the test pilot and HTD. Because of the small sample size, the assumption of normality may be violated; therefore, nonparametric methods were used for testing comparative measures. A matched pair Wilcoxon test was implemented. Pairs were associated by speed and braking condition, yielding nine pairs. A significance level of $\alpha=.05$ was set *apriori*. Correlations were also made between the test pilot and HTD's trunk kinematics using Spearman's rho.

## RESULTS

**Table 1** displays the speed of the power wheelchair for each braking/initial velocity condition as well as the trunk kinematics of the test cases. No statistical differences (p=.260) were found in the wheelchair speed at brake initiation between riders. Analysis of the trunk angular displacement between the test pilot and HTD revealed no statistical differences (p=.051). Significant differences were present in the trunk angular velocity (p=.011) and trunk angular acceleration (p=.021) between test cases. **Table 2** lists Spearman's rho for correlations between the test pilot and HTD's trunk angular displacement, velocity, and acceleration.

| | Speed (m/s) | | TAD (°) | | TAV (°/s) | | TAA (°/s$^2$) | |
|---|---|---|---|---|---|---|---|---|
| | TP | HTD | TP | HTD | TP | HTD | TP | HTD |
| Slow JR | .78 | .76 | 5.5 | 5.9 | 39.4 | 32.1 | 532 | 431 |
| Med. JR | 1.46 | 1.38 | 13.3 | 5.3 | 26.0 | 26.0 | 427 | 289 |
| Fast JR | 1.87 | 1.97 | 9.4 | 9.7 | 32.7 | 24.4 | 479 | 253 |
| Slow FR | .77 | .76 | 9.1 | 9.2 | 41.6 | 35.2 | 511 | 515 |
| Med. FR | 1.35 | 1.38 | 15.4 | 6.3 | 55.0 | 28.6 | 354 | 397 |
| Fast FR | 1.90 | 1.97 | 68.7 | 52.5 | 171.3 | 64.5 | 558 | 409 |
| Slow EPO | .77 | .76 | 41.3 | 11.9 | 77.6 | 42.2 | 763 | 715 |
| Med. EPO | 1.35 | 1.38 | 78.6 | 18.6 | 184.8 | 44.3 | 1229 | 641 |
| Fast EPO | 1.88 | 1.97 | 74.6 | 65.7 | 192.5 | 113.9 | 824 | 606 |

Table 1. – The means of the wheelchair speed at brake initiation, trunk angular displacement (TAD), velocity (TAV), and acceleration (TAA) are compared between the test pilot (TP) and Hybrid III Test Dummy (HTD) for joystick release (JR), full reverse (FR) and emergency power-off (EPO) braking conditions.

## DISCUSSION

The trunk angular displacement, velocity, and acceleration are measures of the trunk stability of the test cases. The trunk displacement was found to be similar over a range of speeds and decelerations. This is promising evidence that the test dummy can be a suitable surrogate for a wheelchair user in low speed dynamic studies. These statistical similarities were weak; however (p=.051), and differences were more prominent for the successive time derivatives of displacement. Spearman correlation coefficients of the trunk angular kinematics were moderately strong. This indicates that while the response is not an exact match, motion of the wheelchair user can be predicted from the HTD.

Future studies will utilize a dynamic model to ascertain specific parameters of the test dummy. This will determine if differences in the response are attributable to mass/anthropometry. Other areas of research include computer modeling to predict the outcomes of wheelchair driving accidents. This modified HTD is intended for use in wheelchair crash prevention studies. A reliable and accurate dummy is necessary for valid results and ultimately the reduction in accident frequency and severity.

| | TAD | TAV | TAA |
|---|---|---|---|
| $r_s$ | .767 | .917 | .817 |

Table 2. – Spearman's rho for trunk angular displacement (TAD), velocity (TAV), and acceleration (TAA).

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# EFFECT OF GLOVES ON WHEELCHAIR PUSHRIM KINETICS IN A HETEROGENOUS POPULATION

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## ABSTRACT

Adaptations to the hand-pushrim interface may significantly alter forces produced at the pushrim during manual wheelchair propulsion. This study measured the wheelchair pushrim forces of five men with different levels of spinal cord injury who were experienced in wheelchair propulsion. Tangential force and propulsion efficiency were calculated at two speeds, 2 mph and 4 mph. There was no significant difference in tangential force or efficiency using gloves compared to not using gloves at either speed. This does not support the findings of previous similar studies.

## BACKGROUND

Manual wheelchair users rely on the health of their hands and arms for most daily activities and leisure pursuits. Researchers have postulated that repetitive use injuries in this population may be due to forces not directly generating propulsion, such as those required to maintain grip on the pushrim. Some have demonstrated that modifying the hand-pushrim interface will reduce excessive forces during propulsion. This effect can be seen in studies comparing vinyl-coated versus anodized pushrims[1,2] and gloved versus barehanded propulsion[2,3]. Shimada et al.[3] used a repeated measures design with seven subjects and found that tangential force in wheelchair propulsion was significantly larger when subjects used gloves. They also found a trend towards greater mechanical efficiency with glove use. Souza et al.[2] demonstrated similar findings in a much larger sample size of 48 without using a repeated measures design. Both studies used subjects with spinal cord injuries of T4 or below, therefore the results are generalizable only to this population.

## RESEARCH QUESTION

Do the findings of previous studies examining the effect of gloves on wheelchair propulsion translate to a more heterogeneous sample of subjects? We hypothesize the tangential force and efficiency of propulsion will increase with the use of gloves at both 2 mph and 4 mph in both spinal cord injury and multiple sclerosis subjects.

## METHOD

*Subjects*: The subjects were 5 male veteran volunteers with spinal cord injuries (4 with paraplegia, 1 with tetraplegia) that were experienced manual wheelchair users. Informed consent was obtained prior to the collection of data.

*Experimental Procedure*: A SMART$^{Wheel}$ force and torque sensing pushrim was installed on the dominant hand side of the subject's own wheelchair and set up to collect pushrim force data at 240 Hz. The subject was then transferred onto a roller system. The roller system allowed wheelchair propulsion without forward movement. After allowing the subject to practice propelling to insure maximum comfort, test data was collected. The first test consisted of 20 seconds of propelling at 2 mph. The second test consisted of 20 seconds of propulsion at 4 mph. This was repeated both with and without the use of standard fingerless leather wheelchair gloves. The test sequence was randomly selected.

*Data Analysis*: Tangential forces were calculated using coordinate data collected from the SMART$^{Wheel}$. Maximum propulsion efficiency was calculated from the ratio of tangential force to total force. Average maximum peak forces for 5 propulsion cycles were used from each study condition. A student's t test was used to compare mean peak forces with and without gloves at 2 and 4 mph.

## RESULTS

A comparison for both gloved and non-gloved is shown for subject 3 in Figure 1. Note that the different trials are not synchronized to each other.

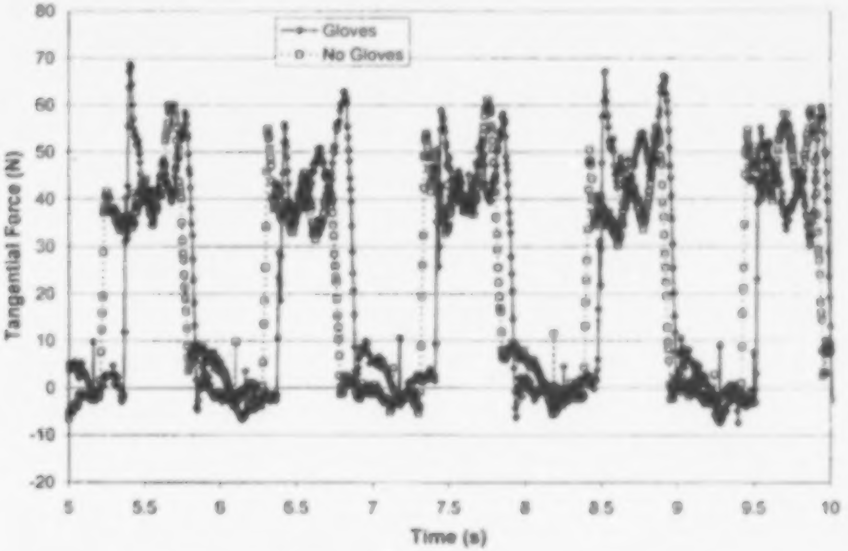

**Figure 1. Tangential Force for Subject 3 at 2 mph.**

The resulting group averaged peak tangential forces and efficiencies for 5 propulsion cycles are shown in Table 1.

**Table 1. Tangential Forces and Mechanical Efficiency During Propulsion**

| Subject/ Diagnosis | Tangential Force (N) | | | | Mechanical Efficiency $Ft^2/F^2$ (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 mph | | 4 mph | | 2mph | | 4 mph | |
| | gloves | no gloves | gloves | no gloves | gloves | no gloves | gloves | no gloves |
| 1/ T10 SCI | 48.25 | 47.30 | 117.80 | 60.92 | 35.7 | 41.9 | 90.4 | 44.3 |
| 2/ T12 SCI | 88.64 | 83.29 | 120.98 | 113.19 | 81.2 | 84.5 | 84.7 | 69.0 |
| 3/ T11 SCI | 63.48 | 57.50 | 75.42 | 70.80 | 81.9 | 82.7 | 76.9 | 76.4 |
| 4/ C6 SCI | 69.67 | 31.40 | 84.00 | 94.29 | 68.4 | 79.9 | 72.7 | 72.5 |
| 5/ T6 SCI | 46.63 | 42.24 | 69.94 | 77.20 | 83.7 | 81.8 | 85.0 | 83.0 |
| t-test for grouped data (p value) | 0.751 | | 0.110 | | 0.375 | | 0.504 | |

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Although there was a trend in some conditions toward greater tangential forces and efficiency in the gloved trials, these findings were not significant, i.e. $p \leq 0.05$ (tangential force at 2 mph $t = 0.37$, at 4 mph $t = 0.50$; efficiency at 2 mph $t = 0.75$, at 4 mph $t = 0.11$).

## DISCUSSION

Previous studies have found a significant difference in the forces generated during propulsion of wheelchairs with and without gloves in homogenous populations, i.e., men with T4 or below spinal cord injuries. This study used a similar protocol but with a heterogeneous population of wheelchair users (men with multiple sclerosis or spinal cord injury of any level of spinal cord injury able to propel at 4 mph) and found no significant differences in peak tangential force or efficiency using gloves. There were some subjects that demonstrated a pronounced difference when using gloves but these findings did not hold when grouped with the rest of the population. Currently, the results presented are limited by the small sample size. However, it is important to note that data collection in this study is ongoing. Our expected data set will consist of peak forces measured during a full 20-second propulsion for each condition in 20 subjects. By the end of data collection we expect there will be sufficient power behind the results to support or refute the hypothesis. In addition, we will look at whether subjects with multiple sclerosis or tetraplegia had different propulsion forces compared to subjects with lower level spinal cord injury. If the final data analysis supports the hypothesis, it will add weight to findings from previous studies by demonstrating the effect in a varied population.

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# RELATIONSHIP OF WHEELCHAIR PUSHRIM FORCES AND PRESSURES AT THE BODY-SEAT INTERFACE IN MANUAL WHEELCHAIR USERS

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## ABSTRACT

Understanding the relationship of pushrim forces and the pressure at the body-seat interface during the propulsion cycle will provide information about possible injurious loads that lead to pressure ulcerations. A study was conducted using male subjects who rely on manual wheelchairs for community and household mobility. This study simultaneously measured the wheelchair pushrim forces, body-seat interface pressure, and upper extremity motion during wheelchair propulsion. Vertical pushrim forces and peak pressure during propulsion were compared for temporal correlation. Additionally, the average value of the peak pressure differential, $P_{max}-P_{min}$, during 5 propulsion cycles was found to decrease as the mechanical efficiency increased.

## BACKGROUND

Manual wheelchair users (MWU) frequently experience pressure ulcerations at the body-seat interface. The development of pressure ulcerations in MWU can be effected by factors such as normal and shear forces at the body-seat interface. It has been reported that as many as 85 percent of all persons with spinal cord injury develop pressure ulceration during their life time (1). Preventative measures in the form of custom designed wheelchair cushions, manufactured to help distribute the load more evenly, have been the focus of research. However, the prescription of custom cushions alone may not reduce the occurrence of pressure ulcerations since some studies have shown that peak pressures were not significantly different or reduced between various types of cushions (1-2). Additionally, most of the body-seat interface force studies have been completed under static sitting conditions.

Boninger et al. devised a method to measure the gross mechanical efficiency during wheelchair propulsion. Mechanical efficiency is defined as the ratio of tangential force to the total force (3). In addition, Rorrer et al. examined the dynamic body-seat interface pressures and the upper extremity motion during propulsion and determined that there was a temporal relationship between the vertical displacement of the trunk and dynamic pressure (4).

However, the above studies stop at the study of the upper extremities, and although Rorrer et al. studied the relationship between motion and pressure, forces at the pushrim were not included in the study. Therefore, a study that relates the pushrim forces and mechanical efficiency during propulsion to the dynamic behavior of pressure at the body-seat interface will further our understanding of the user-machine interactions and potential causes of pressure ulceration.

## RESEARCH QUESTION

The goal of this study was to evaluate the relationship between pushrim forces and the pressure at the body-seat interface during propulsion. The hypotheses for this study are:

1. A direct relationship exists between the vertical and forward pushrim forces and the body-seat interface pressure; that is, the pressure will decrease during a propulsion cycle and increase during the recovery cycle.

2. Higher propulsion efficiency will result in decreased pressure differential.

## METHOD

*Subjects*: 4 male veterans with spinal cord injuries who rely on wheelchairs for community and household mobility participated in this study. All subjects used custom fitted wheelchairs. All subjects signed a consent form before study was conducted.

*Experimental Procedure*: Vicon Motion Analysis, Force Sensing Array (FSA) pressure sensing system, and the SMART$^{\text{Wheel}}$ were used to collect kinematics data at 120 Hz, pressure data at 10 Hz and pushrim force data at 240 Hz, respectively. The frequencies of the data collection are multiples of 12 in order to allow linear interpolation between data points during post data analysis. All software was synchronized using a mechanical switch to start data collection at the same time.

24 reflector markers were placed on subject's head, shoulder, elbow, wrist, metacarpal, axle and wheels. A 16 x 16 inch FSA mat was placed over the wheelchair cushion. Subjects used their own wheelchair cushion. The SMART$^{\text{Wheel}}$ was equipped on the dominant hand side of the wheelchair. The subject was then transferred onto a roller system. The roller system allowed wheelchair propulsion without the forward movement. The subject was instructed to remain seated on the FSA mat for 15 minutes in order to allow the FSA mat to reach a steady state. After allowing the subject to practice propelling to insure acclimatization, three tests were performed. The first test consisted of a 20 second static test, during which time pressure data was collected. The second test consisted of four 20-second dynamic tests. During the dynamic test, motion, pressure and force data were collected for 2 mph and 4 mph propulsion with and without the use of standard wheelchair gloves. The test sequence was randomly selected out of possible 24 sequences. Only the data from 4 mph propulsion without gloves was used for this study.

*Data Analysis*: 5 propulsion cycles were analyzed for this study. The tangential ($F_t$), radial ($F_r$), and axial ($F_a$) were calculated from the forward, axial, and vertical forces, $F_x$, $F_y$, and $F_z$ respectively that were obtained using the SMART$^{\text{Wheel}}$. The point of force application on the pushrim was taken to be the 2$^{\text{nd}}$ metacarpal marker coordinates in the saggittal plane. Mechanical efficiency was then calculated using efficiency = $F_t^2/F^2$, where $F^2 = Fx^2 + Fy^2 + Fz^2$. A pressure cell that represented the region where peak pressure occurred during propulsion was chosen for analysis.

## RESULTS

Figure 1 shows the temporal relationship between the body-seat interface peak pressure and the pushrim forces in the x and z directions. The maximum pressure is observed during the recovery cycles and minimum pressure is seen during the push cycles. Table 1 lists the average values for maximum tangential forces, the mechanical efficiencies, pressure differential, and maximum vertical force during 5 propulsion cycles for each subject.

We were unable to reliably sample the pressure measurement mat above 10 Hz. This results in a significant difference in sample rate between the mat (10 Hz) and the Smart$^{\text{wheel}}$ (240 Hz). Despite the fact that both samples were synchronized the resulting dearth of data during the push phase (3-4 data points made temporal correlations relatively meaningless.

## DISCUSSION

It was originally hypothesized that both the vertical force in the push portion of the propulsion cycle and the mechanical efficiency would be related to the pressure change. Even though it appears from Figure 1 that maximum pressure drop occurs during the peak vertical force, this is not consistent over the subject population. Mechanical efficiency correlated strongly to body-seat interface pressure. This finding suggests that the more efficient the MWU is in propelling the wheelchair, the smaller the pressure differential is during the propulsion cycle. It is not known if this smaller pressure differential is protective to weight-bearing tissues. However, the goals of distributing the body-seat interface pressure and decreasing peak body-seat interface pressures have been consistent throughout the literature to decrease the risk of PU. If diminishing the pressure differential during propulsion were desirable, then based on this data, training the MWU in a more efficient stroke would support more desirable interface pressures during the dynamic conditions of propulsion. Currently, these results are limited by the small sample size. However, it is important to note that data collection in this study is ongoing.

**Table 1. Correlation of Pressure Change**

| Subject | $F_t$ (N) | Mech. Eff. | ΔP (mm Hg) | $F_z$ (N) |
|---|---|---|---|---|
| A | 60.92 | .443 | 129.6 | 89.4 |
| B | 113.1 | .690 | 98.2 | 105.7 |
| C | 80.80 | .764 | 58 | 82.8 |
| D | 94.29 | .724 | 68 | 98.7 |
| Correlation to ΔP | -0.36 | -0.93 | 1 | 0.17 |

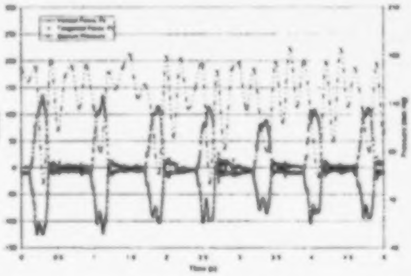

**Figure 1. Body-Seat Interface Pressure and Pushrim forces for Subject B.**

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# A VIDEO-BASED ANALYSIS OF "TIPS AND FALLS" DURING ELECTRIC POWERED WHEELCHAIR DRIVING

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## ABSTRACT

Each year over 36,000 wheelchair-related accidents cause injury to wheelchair users. Most of these accidents can be attributed to tips and falls. The purpose of this investigation was to determine if seatbelt use and proper legrest adjustment decreases the frequency and severity of electric powered wheelchair (EPW) tips and falls. The response of a Hybrid II test dummy was video-taped while driving over commonly encountered obstacles while varying speed, legrest height, and seatbelt use. 73% of falls occurred at the 2m/s speed, 100% of falls occurred when the seatbelt was off, and 100% of falls occurred when the legrests were off. Seatbelt use and proper legrest height offers greater safety to the EPW user, however, some adverse events occur despite their proper use.

## INTRODUCTION

In the United States, an average of 36,559 wheelchair-related accidents each year are serious enough to require the user to seek attention in an emergency room (1). In addition, an average of 51 deaths are caused by wheelchair-related accidents each year (2). Between 1973 and 1987, there were 770 wheelchair-related deaths reported to the United States Consumer Product Safety Commission (USCPSC), 68.5% of which were attributed to falls and tips (2). Of the 2,066 non-fatal accidents reported between 1986 and 1990 to the USCPSC, falls and tips were the cause 73.2% of the time (1). An estimated 24.6% of wheelchair-related accidents involve EPWs (3).

Users of EPWs often have difficulty maintaining a supported seated posture when subjected to external forces (4). These external forces can be induced by ordinary obstacles which an EPW user encounters everyday thus exposing them to the risk of falling from the EPW or completely tipping the EPW. Further increasing the risk to EPW users is the lack of seatbelt use and/or the use of improperly adjusted legrests.

With the incidence of tips and falls in the EPW population, there is a need to characterize the cause of these adverse events. The purpose of this investigation was to qualitatively measure the response/motion of a test dummy while traversing common obstacles encountered by EPW users to determine if optimal wheelchair fit, the use of seatbelts, and driving speed effect the frequency and severity of EPW tips and falls.

## METHODS

*Test Dummy.* A 50th percentile anthropometric Hybrid II test dummy (HTD) was used to simulate a person driving an EPW. This HTD has been used in previous studies of wheelchair stability and has been shown to emulate a subject with T8 paraplegia caused by traumatic spinal cord injury (4). The HTD was clothed to provide proper seat friction and was checked for proper starting position prior to each data collection trial.

*Test Wheelchairs.* Four different EPWs were evaluated in this investigation: The Quickie P100, the Quickie P200 (Sunrise Medical Inc.), the Action Storm (Invacare Corp.), and the Jazzy 1100 (Pride Mobility). These models are among the most commonly used in the world. Seating dimensions and backrest angle of all EPWs were consistent. The Jazzy 1100 is equipped with its own seating system and was used for testing. A 50 mm linear foam cushion fitted with a nylon cover was used as the cushion of the other EPWs. Tires were inflated to rated pressure and the batteries were charged to at least 75% prior to each data collection period. The EPWs were calibrated to a maximum speed of 1m/s or 2m/s while driving on a level tile surface and were operated via a radio control model airplane controller (Figure 1). Speed was verified pre and post-obstacle driving.

*Test Obstacles*. The EPWs were driven over four commonly encountered obstacles: A door threshold (12mm high x 100mm long x 900mm wide), a standard ADA curb-cut, a five-degree ramp, and a 50mm curb. The curb-cut, ramp, and curb were tested in both ascending and descending conditions. Additionally, the curb was addressed perpendicularly as well as at an approximate 45 degree angle.

*Test Protocol*. To assess the fit of the EPW and the use of seatbelts each obstacle was traversed with and without a seatbelt with the legrests adjusted properly, with the legrests too high, with the legrests too low, and without the legrests. For the purposes of this study, properly adjusted legrests allowed the feet of the HTD to rest flat on the footrests with the thighs of the HTD within +/- 5° of the seat angle. Legrests too high was defined as a gap of 10 to 20mm between the bottom of the HTD thigh and the front edge of the seat cushion. Legrests too low was defined as the point where only the balls of the HTD feet touched the footrests.

Each EPW with the HTD was driven over each obstacle at each speed for each condition three times for a total of 432 trials per EPW. All trials were video-taped (Sony Video 8, video camera recorder) at an offset angle approximately 30 degrees from the plane of action. The videotapes were then reviewed and each trial was scored on an ordinal/nominal scale using the following notation: "N" for no fall; "L" for loss of control (e.g., The HTD falls forward or sideways but remains in chair); "F" for fall; and "T" for a complete tip of the EPW.

*Statistical Analysis*. The N, L, F, and T notation was transformed to an ordinal severity scale of 1, 2, 3, and 4, respectively. The data were initially analyzed on a univariate basis using Fisher's exact tests and frequency distributions. Because significant differences were found, the interactions between EPW, speed, legrest condition, seatbelt use, and obstacle were analyzed. A mixed model analysis was performed taking into account all the aforementioned variables with N, L, F, and T as the outcome. Significance was set at the p=0.05 level.

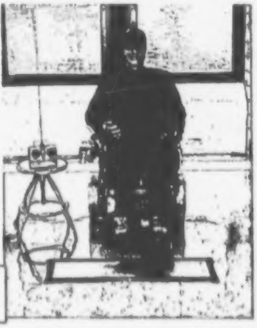

Figure 1. HTD, remote control, and door threshold

## RESULTS

The results of the univariate statistical analysis indicate significant relationships between the problems encountered (e.g. L, F, and T) and four of the five studied variables ($p<0.05$). Speed was not significantly related to the problems but is notable. Table 1 describes these results for the more prominent relationships indicating that 73% of falls occur at the 2m/s speed, 100% of falls occur when the seatbelt is off, 100% of falls occur when the legrests are off, and the three obstacles most likely to induce a fall or loss of control are the ascending curb cut, ascending curb at 45°, and descending the ramp. In addition, 89% and 11% of falls occurred in the P200 and P100 chairs, respectively.

The mixed model analysis confirms the significant relationships between the problems encountered and the EPW, legrest condition, seatbelt use, and obstacle ($p<0.05$). However, the mixed model indicates no significant relationship between the problems encountered and driving speed. This analysis also indicates a relationship between the problems encountered and the obstacles but no one obstacle was designated to be the most problematic.

| | **Speed** | | **Seatbelt** | | **Legrest** | | **Obstacle** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Problem** | 1m/s | 2m/s | On | Off | Proper | Off | Ccup | Curbup | Rampd |
| **LOC** | 54.5 | 45.5 | 39.8 | 60.2 | 12.5 | 45.0 | 10.2 | 11.36 | 25.0 |
| **Fall** | 33.3 | 67.7 | 0 | 100 | 0 | 100 | 40.0 | 20.0 | 30.0 |

Table 1. Univariate comparison (percentages) of problem encountered and different variables. LOC, loss of control; Fall, fall from chair; Ccup, ascending curb cut; Curbup, ascending curb at $45^{\circ}$; Rampd, descending ramp.

## DISCUSSION

The results of this investigation demonstrate that the use of legrests and seatbelts prevent the HTD from falling from the EPW while traversing common obstacles at one and two m/s. This finding is consistent with previous research (4). Both legrests and seatbelts provide restraint and, therefore, prevent ejection of the HTD from the EPW (5). For the same reason, less HTD loss of control occurs with the use of legrests and seatbelts.

The mixed model analysis indicates that speed is not the most important determinant of falls and loss of control. Other determinants such as legrest and seatbelt use and obstacle type are more indicative of adverse events occurring.

## CONCLUSION

This investigation demonstrates that proper legrest adjustment and seatbelt use offers the EPW user greater safety when traversing common obstacles. All falls of the HTD from the EPWs occurred during the no legrest and no seatbelt trials. Additionally, loss of control of the HTD was significantly reduced when legrests and seatbelts were in use.

## ACKNOWLEDGEMENTS

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# A POWER-ASSISTED SYSTEM FOR A THAI STYLE TRICYCLE

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## ABSTRACT

This paper presents a design of a power-assisted system for a Thai style tricycle. The added-on electrical propulsion module is mounted on one of the rear wheel, and the other wheel is driven by manpower. A speed and current measuring devices are interfaced to a micro-controller control unit, which automatically control motor torque during each mode of transportation. The main purpose of design is to increase safety during transportation and independent in mobility for the disabled young children and aged people. It is shown that they can use this tricycle for daily outdoor activities with more convenience.

## BACKGROUND

In developing country liked Thailand there are very few alternative choices for disabled people, especially for the outdoor transportation. From the information gathered, the self-propelled or a "push-pull tricycle" (Fig.1) is only one choice which is developed from the bicycle since last 20 years ago and are mainly used in this region. The uniqueness arises from its simple structure and its various applications. Some of its advantages are that they are lighter in weight, easy to maneuver, less costly, and more acceptable than other types of vehicles. Annually, around 1500 units of this tricycle have been donated via Department of Public welfare, Ministry of Labour and Public Welfare to the disabled in each provinces in Thailand. Also, some disabled people use an engine type tricycle, which is modified from the motorcycle, since it has better cruising and uphill climbing performance. However, it requires an intensive skill and license for riding. It was deemed inappropriate for disabled young children and old woman. Now the user is mainly limited only to the man. Furthermore, with the economic crisis causes the problem of funding constraint and the insufficient of infrastructure development comes to be more serious, the expensive cost of the imported power vehicles is also the main barrier. In order to allow the disabled children to experience movement and control which can facilitate their social, cognitive, perceptual and functional development, and also increase independence in mobility for the aged person, a self-propelled tricycle stills come to be a suitable solution (1). However, the primary problems for those people when riding on this conventional tricycle are the safety and durability of riding. Since they can not exert the sufficient force, consequentially the cruising and climbing performance is too low. Especially, the geography of Bangkok is mainly a terrain across the canal. As a result, a power-assisted system comes to be a necessary solution for those people (2).

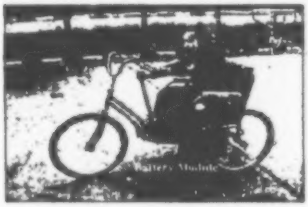

Fig 1 : Thai style tricycle with power assisted system

## DESIGN

**Mechanical parts:** As shown in Fig.2, the propelling structure of the conventional tricycle is including the push-pull stick, transmission bar and disc in the same manner as the stream train. The manpower push-pull force is transmitted to the rotating transmission disc via the

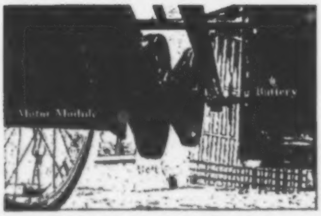

Fig. 2 (a) Mechanical module

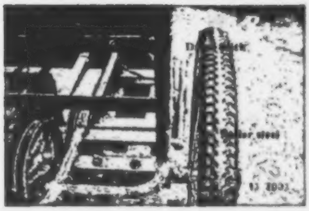

Fig.2 (b) Mechanical module

transmission bar. The wheel is rotated according to the push-pull frequency of the user. Steering is accomplished by turning the handlebar connecting to the single front wheel. The direction of movement will be forward or backward direction depends upon the stick is pushed or pulled in the first stroke respectively. By comparing to the pedaling tricycle, it is much easier for backward movement and turning in a narrow space.

The proposed added-on propulsion system is mainly controlled through the belt drive as shown in the Fig.2, which uses a belt to connect a pulley on the wheel axle to the motor pulley. It is modular construction and consists of a permanent magnet 24 V 600 W DC motor, which is powered by a pair of 12 V 35 Ah sealed lead acid batteries and mounted under the seat. Based on the requirement of speed and torque, 2 sets of pulley with 4:1 gear ratio is coupled in cascade, so that total gear ratio becomes 16:1. Also, there is a drive stick beside the seat, which is design for connect or disconnect the motor drive module to the wheel axle. By pulling up the stick, the motor module is pushed by the steel roller, the belt between wheel and motor pulley is stretched and motor torque can be transmitted to the wheel (driving mode). On the other way, by pushing down the stick, the motor will be disconnected from the wheel in order to change to the manual operation without any friction from the motor. This stick can be also used for emergency whenever the controller is uncontrollable too.

**Electrical parts :** The controller is based on the micro-controller (PIC16C73) of Microchip which gives them much more flexibility and many parameters setting to accommodate various individual needs. It is installed under the seat with the main switch and circuit breaker. The main part of the power circuit is the H type full bridge MOSFET operated by PWM signal with 20 kHz switching frequency that outside the hearing range of most individual. By pressing the enable switch at the push-pull stick, the control unit will check the push-pull frequency and motor current in order to calculate the desired torque and speed from the motor side. Basically, the control mode can be divided into 2 modes according to the dip switch setting as follows: (1) 2 strokes: the motor turns on whenever the user pressed the enable switch and turns off when releases the switch, (2) 4 strokes: when the switch is pressed once the motor turns on and remains on, and when the switch is pressed again the motor turns off.

**Other features**

**(1) Power-assisted system:** The push-pull frequency detector is attached to the transmission disc as shown in Fig. 3. It consists of 2 LED sources which is located 90 degree (electrical) apart from each other and the white color sticker strip adhere to the transmission disc. Whenever, the transmission disc is rotated by 1 turn, the pulse signal called "A" and "B" which have 12 pulses/round will be sent from the detector to the control unit to generate the speed command and rotating direction of the motor. The ratio of the motor force and manpower force (electrical gear) can

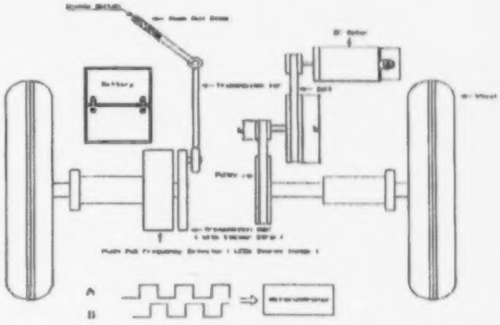

Figure 3 : Push-pull frequency detector circuit

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be selected by the dip switch (2:1 to 4:1). Furthermore, the controller will check the magnitude of the motor current or load to compensate the torque command as shown in Fig. 4. During uphill climbing, the torque command is boosted while the downhill climbing, the regenerative brake is generated to decrease the torque. By comparing the push-pull frequency to the present speed command every sampling time (5 msec), the controller will update the motor force.

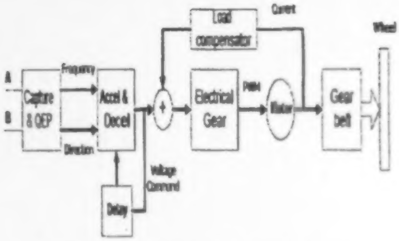

Fig 4 : Block diagram of the control unit

**(2) Sensor failure** : During pressing the enable switch, if non-signal period from the detector exceeds the setting period, the control unit will send warning signal showing failure in the detector circuit. If the user can not find any causes, user can change to motor driving mode by setting the dip switch.

**(3) Protection and indicator** : The controller is also designed to have some necessary protection features such as (1) Over load (2) Current limit (3) Over temperature (4) Battery polarity protection (5) Maximum speed limitation and (6) LED status indicator

## RESULTS

The power-assisted system was installed to the conventional tricycle as shown in Fig.1. An experimental result with the power-assisted system compared to the conventional one was collected and the performance of the system is shown below. The experiment is implemented on the usual flat concrete road with 60 kg rider.

| | |
|---|---|
| Vehicle speed : | The maximum cruising speed is increased from the 10 km/hr to 20 km/hr. |
| Acceleration : | With the rating torque from the motor around 18 nM, the time consumes for accelerate from 0 to 10 km/hr is decreased from 15 sec to 7 sec. This makes it more safety when transport on the usual traffic. |
| Cruising distance : | The distance is extended around 45 km under power-assisted mode. (electrical gear = 2:1) |
| Uphill climbing : | With the load compensate function, it can run over the usual 12 % (tan θ) terrain. |
| Braking distance : | With regenerative brake, around 3 meters of braking distance can be achieved. |

## CONCLUSION

The design of the power-assisted system for Thai style push-pull tricycle has been presented. The system is based on modular construction of the motor, pulley and the micro-controller based control unit. From the testing result, it is also shown that the disabled young children and aged persons are able to drive the tricycle and reach places without having to rely on public transportation which give the greater degree of independence.

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## ACKNOWLEDGMENTS

This project is a cooperation with the Thai with disability foundation who supports the information, the tricycle and testing result.

# 24 HOUR POSITIONING- THE MISSING LINK

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## ABSTRACT

"The American Dream." Everyone is well aware of the importance of a good night's sleep. However, this is a neglected concept for individuals with physical disabilities and for their caregivers. This paper discusses the necessity of maintaining a symmetrical posture through 24 hours of the day, and of extended sleep periods. The Dreama™ sleep and rest system is then described as a solution to this problem.

## BACKGROUND

Dr. Nathaniel Kleitman first recorded the importance of sleep in 1920 (1). His discovery of sleep cycles, dreams, sleep deprivation, sleep disorders and the REM sleep stage indicated that sleep is the brains' more active state and has a restorative effect on the body. Kleitman and his team recorded four important stages of sleep, from starting to relax and decreasing heart rate through to REM sleep. They found that on average, a person goes through 5-6 sleep cycles a night, with each subsequent REM stage becoming longer, taking 90 minutes to achieve the REM stage. It is during this restorative sleep that the human growth hormone is released and cells of the immune system are stimulated (2).

During restorative sleep muscle and bone mass are developed, old cells are replaced with new, and organs are re-energized. Without sufficient restorative sleep the individual may experience a decrease in reflexes, motivation and cognitive skills, along with an increase in irritability and anxiety (1). The amount of sleep needed by an individual decreases from 16 hours/day as a newborn, to 10-12 hours/day between ages 6-12 years, to 9-10 hours/day as a teenager and finally 7-8 hours/day as an adult. It has been stated that people who have less than 6 hours of sleep a night are at a higher risk for cancer, heart disease and stroke (2).

## STATEMENT OF THE PROBLEM

Restorative sleep is essential for people with physical disabilities in order to repair soft tissue trauma that may have occurred during the day, due to factors such as asymmetric posture, abnormal muscle tone, and inability to shift position. For children there is the additional concern of asymmetrical postures growing into fixed deformities during puberty, and any dislocated joint developing incorrectly.

In response to these needs there are many daytime positioning systems, designed to maintain a symmetrical posture, increase joint range of motion, decrease stiffness and pain and promote body system functioning of the individual. However, this cannot be said for nighttime positioning, although the individuals needs continue through 24 hours of the day. There are very few sleep and rest systems on the market, therefore most solutions have to involve the ineffective use of wedges, beanbags, pillows and rolled towels.

Symmetrical positioning during the night is as important, if not more so, than during the day, because of the amount of time a person with a physical disability spends in their bed due to such factors as reliance on caregivers, intermittent resting and feeding needs.

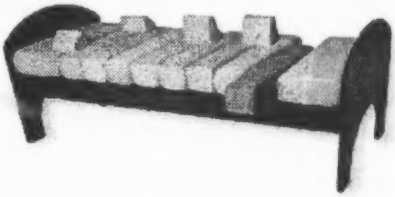
## DESIGN DEVELOPMENT

Jenx® recognized the need for a sleep/rest positioning system and so conducted market research, which indicated that 74% of caregivers questioned stated that they wanted some sort of nighttime positioning system, the device had to be quiet and easy to use, it had to fit on an ordinary bed and be easy to clean.

Conditions that the system was designed for include neurological conditions involving abnormal muscle tone/weakness, post surgery/trauma situations requiring joint stabilization, arthritic or rheumatoid conditions for joint support and pain prevention, and any condition requiring support of posture at rest, either temporary or permanent.

The goals of the system are to continue the good positioning achieved during the day, maintain joint range of motion, reduce stiffness/pain, promote body system functioning, and extend sleep periods of the individual and caregiver.

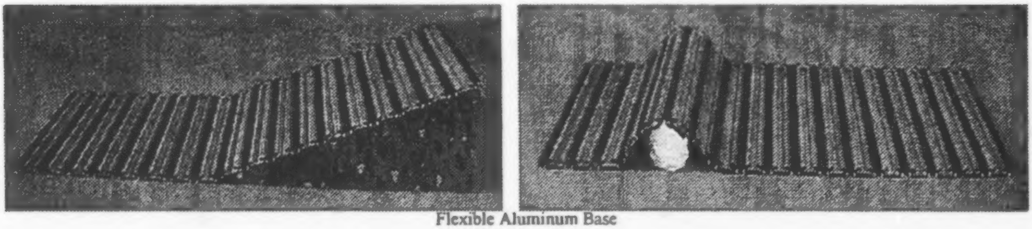
From this research The Dreama™ was developed:



The Dreama™

## THERAPEUTIC FEATURES

The flexible aluminum base allows for easy management of aspiration, reflux, edema and fixed contractures by contouring around hospital beds, wedges and rolls. There are two sizes available: standard crib and standard twin bed.

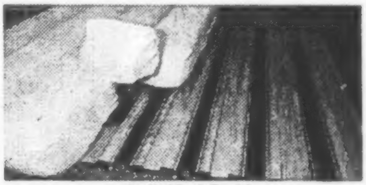


Flexible Aluminum Base

The individual cushions attach to the tracks along this base, which encourages air circulation and allows for quiet removal when that section is soiled, while eliminating the need to disturb the user. The cushions are made from pressure-relieving foam, lined with a hypoallergenic, latex free material and have terry-cloth removable covers to promote good skin integrity.

Optimum positioning of the individual is achieved in either prone, supine or side lying with the Glide-Lock™ support pads. The pads glide quietly in a track between the individual cushions and lock securely in place.

Glide-Lock™ Support Pad



Individual Cushions

There are also hoops and an abduction block available as accessories.
The system is easily cleaned with soapy water and the covers are machine washable.

## RESULTS

A single case, experimental design pilot study was conducted by a physical therapy student in England to establish the effects of the Dreama™ on a child with spastic quadriplegia cerebral palsy. Hip abduction, number of times awake during the night and qualitative statements from the parents were recorded after 1 week of using the Dreama™ with the following results:

| | Times | Hip | Abd |
|---|---|---|---|
| Day | Awake | AM | PM |
| Mon | 6 | 25° | 35° |
| Tue | 3 | 25° | 40° |
| Wed | 3 | 35° | 40° |
| Thur | 4 | 35° | 45° |
| Fri | 2 | 45° | 40° |
| Sat | 4 | 40° | 40° |

Qualitative findings from the parents comments included; "Carrying has become easier." "Better mouth closure during feeding." "Becoming more vocal." "His legs are as flexible as when he has had Botox." "He's trying harder to roll over."

## DISCUSSION

It can be concluded from the study that the Dreama™ seemed to have a positive effect on the subject, however limited conclusions can be made due to the inadequate raw data provided. The observations made during the study however, do support the need for more studies to be undertaken on how correct sleeping positions effect activities during the day.

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## ACKNOWLEDGEMENTS

This paper used the findings from a pilot study completed in January '99 by Michelle Henry, a physiotherapy student, in England: "A Pilot Study to Establish the Effects of the Dreama on a Child with Spastic Quadriplegic Cerebral Palsy: Single Case Experimental Design."

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# TIME SEQUENCE OF PRESSURE CHANGES DURING WEIGHT RELIEF ACTIVITIES ON DIFFERENT WHEELCHAIR CUSHIONS

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+ Touro University College of Osteopathic Medicine, Vallejo, California
* Rehabilitation R&D Center, VA Palo Alto Health Care System, Palo Alto, California

**ABSTRACT:** As part of a larger study of the efficacy of a wearable motion analysis and pressure feedback system, we investigated the use of this system in the spinal cord injured population. In trials with an able-bodied subject, we examined data on pressure reliefs using various shapes of pressure sensor balloons on various types of chair surfaces. We then collected data from five spinal cord injured individuals doing pressure relief exercises, in order to identify characteristic motion and pressure data patterns. We predicted that we could identify correctly performed pressure relief exercises solely from the collected data. Results confirmed that exercises could be distinguished using pressure data if sensors were located so as to obtain unique signatures.

**BACKGROUND:** Individuals with sensorimotor deficits such as spinal cord injury (SCI)[4], stroke, diabetic neuropathy, prolonged post-surgical immobilization and extreme frailty are at risk for the deleterious effects of skin breakdown (i.e. pressure sores) [9]. By frequently performing pressure relief activities, the patient has greater potential for keeping skin intact and preventing hospitalization, thereby reducing healthcare cost and improving quality of life. However, not all patients comply with such regimens [2,5]. Automated devices to enhance compliance have been tried, but are often objectionable to users [7].

We are testing the capability of a computerized wearable motion analysis system ("WAMAS") in conjunction with pressure sensing equipment to allow individuals to self-monitor pressure changes, to give feedback when pressure limits have been exceeded, and to allow health care workers to remotely monitor compliance. In particular, we are testing whether sensors on bed and chair cushions yield sufficient data to estimate risk of skin breakdown; if so, then sensors would not have to be attached directly on non-ambulatory patients. Subjects for this paper were five healthy individuals with long-term SCI referred by VA Palo Alto Spinal Cord Injury Center; later studies will include frail elderly nursing facility residents and peripheral neuropathy patients.

**RESEARCH QUESTION:** Our objective is to test whether the wearable motion analysis and pressure feedback system will produce identifiable patterns that are characteristic of various pressure relief motions [1,3] and can be used to alert clinicians when a scheduled pressure relief is absent.

Although persons in wheelchairs are at highest risk for pressure ulcers at anatomical sites such as the ischial tuberosities and the sacrum, we chose to place pressure sensing balloons (Fig. 1) at mid-thigh so as to not put the individual at further risk for a pressure ulcer. We hypothesized that there are correlations between pressures at the ischial tuberosities and the mid-thigh location (Fig. 2) characteristic of each weight relief activity.

**METHODS:** We analyzed the pressure measurement equipment by focusing on three different variables (1) pressure relief exercises [3] (2) chair type and (3) sensor shape and positioning. Tests were first done with an able bodied person who had no risk of developing a pressure sore during trials that last thirty seconds. This subject had pressure sensors at both high-risk (ischial tuberosity) and low-risk (mid-thigh) sites, in order to demonstrate positive or negative correlations between these locations. The trials were first conducted with one able-bodied individual, repeated at least three times for each variable. With the exception of stand-up, all the exercises performed by the able-bodied person were done solely with upper body strength. In order to simulate the body type of a spinal cord injured individual, the able-bodied person's legs were tied together, and a 30-pound weight was strapped to the lower legs to inhibit motion. The pressure relief exercises were: (1) forward lean, (2) right lean, (3) left lean, (4) push-up, and (5) stand-up. In addition to the various exercises, four types of surfaces were used)[similar to ref. 8]: (1) a plastic chair with no cushion, a wheelchair with (2) a Jay2 cushion (3" thickness, model #S2100, Jay Medical, Ltd., Boulder, CO.), (3) a Roho cushion (3" thickness, Crown Therapeutics, Belleville, IL), and (4) a foam cushion (3" thickness medium density polyurethane, nylon covered, maker unknown. Various sensor geometries were: 2-cm and 3-1/2 cm round balloons, and 3x4 cm and 1.5x2.5 oval balloons, which were equilibrated with atmospheric pressure before each session. Tubing connected the balloon to a solid-state pressure transducer, amplifier and a laptop computer with "ComputerBoards" data acquisition card. For each variation of exercise, chair, and placement of pressure sensors, data were analyzed for mean pressure over the time that the position was held and for duration of the activity.

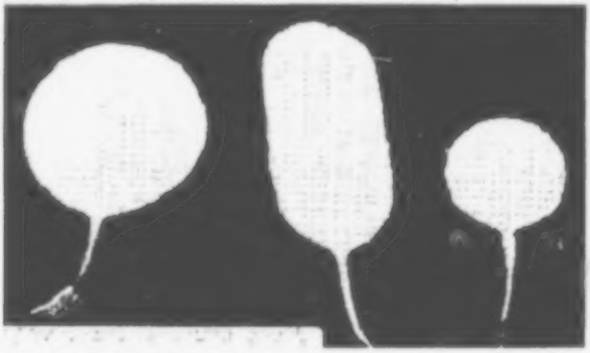

**Figure 1: Pressure-sensing balloons**

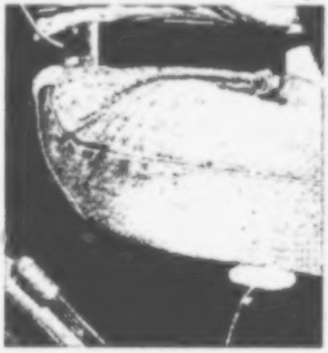

**Figure 2: Typical mid-thigh sensor position**

**RESULTS:** The following table shows pressure change related to in-chair movements comparing ischial tuberosity placement to mid-thigh placement averaged from three trials by one able-bodied subject.

| AVERAGE PRESSURE DURING PRESSURE RELIEF TASKS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MOTION | Ischial tuberosity (mm Hg) | | | | Mid-thigh (mm Hg) | | | |
| | Hard | Jay | Roho | Foam | Hard | Jay | Roho | Foam |
| | * | | | | | | | |
| Right lean | 178 | 29 | 42 | 43 | 33 | 33 | 55 | 52 |
| Left lean | 85 | 121 | 90 | 194 | 238 | 111 | 102 | 138 |
| Fwd lean | 85 | 27 | 44 | 34 | 240 | 112 | 82 | 120 |
| Push up | 85 | 28 | 40 | 60 | 36 | 30 | 42 | 43 |
| Stand up | 85 | 28 | 38 | 30 | 30 | 31 | 38 | 34 |

*note that these data points were taken from the right side pressure sensor, while all other data points were taken from the left side, which explains the increase during right lean (not left lean).

Lateral lean to right or left yields increased pressure at both the tuberosity and mid-thigh on the respective side, forward lean yields lower pressure at the tuberosity and higher pressure at mid-thigh. This shows an inverse relationship when weight is shifted forward and positive correlation during lateral weight shift. The graphs below (Fig. 3) show a discernable pattern for each pressure relief motion. The baseline pressure in each balloon (resulting from crimping or bending after the initial equilibration) is the only significant source of non-zero readings when all weight is off the seat.

**DISCUSSION:** The relationship of ischial tuberosity vs. mid-thigh placement indicates that placement of pressure sensing balloons in the mid-thigh position provides useful information on direction of motion. Among the various types of surface, we observed a consistent pattern for the pressure relief motions across all four types (Fig. 3). Decreases in pressure occurred during each activity at the ischial tuberosities and also at mid-thigh, with the exception being forward lean, which showed an inverse relationship when weight is shifted forward (i.e. increase in pressure due to forward shifting of body weight off the ischium). The time during which pressure is reduced can be used to calculate a pressure relief index [6]. Since the pressure relief activity is transient, one-time or peak pressures are insufficient to indicate the duration of reduced pressure [1].

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**WEIGHT RELIEF PRESSURE vs. TIME**

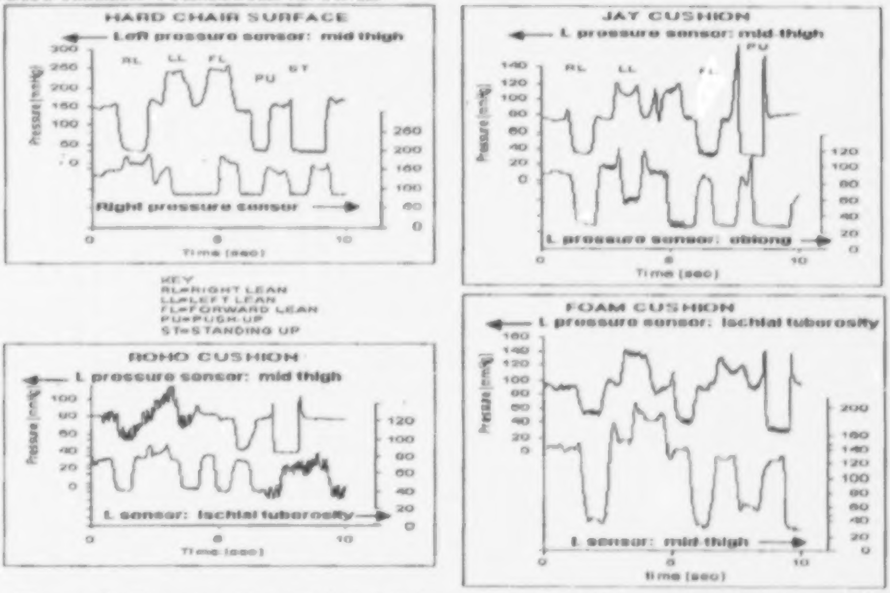

**Figure 3: Pressure from able-bodied subject simulating weight relief exercises**

Actual SCI subjects often did not hold their positions for the recommended 20 seconds (duration of weight relief motion that allows for capillary flow to resume) unless verbally reminded; some used non-standard positions like backward leaning (data not shown). If in clinical use the pressure sensors cannot distinguish such unusual activities, ambiguities could be resolved using motion in addition to pressure data. The results of this study reinforce the idea that the computerized wearable motion analysis system in conjunction with pressure sensors at mid-thigh will produce repeatable patterns useful for monitoring at-risk populations so as to avoid development of pressure sores. This information will contribute to subsequent research to develop technology to monitor compliance with pressure relief in home settings.

**ACKNOWLEDGMENTS:** VA Rehabilitation R&D merit review project E2153TC; VA Palo Alto Rehabilitation R&D Center core support. Address correspondence to: Eric E. Sabelman, VA Rehabilitation R&D Center, 3801 Miranda Ave #153, Palo Alto, CA 94304.

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# RESNA Student Scientific Paper Competition

## Student Scientific Paper Competition
### Sponsored by Whitaker Foundation

On the following pages, you will find the five award-winning papers for the eighth annual RESNA Student Scientific Paper Competition. The student awardee is listed as the first author on each of the papers. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and awards is to encourage and promote student participation in high-quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the RESNA annual conference. This competition is based on scientific merit of the reported research and is structured to be distinct from, and complimentary to, the student design competition.

The winning papers are presented in a special session during the RESNA 2001 Conference. This session provides a unique forum that, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria:

- General quality of the writing and presentation.
- Clear statement of hypothesis or research issues to be addressed.
- Choice and description of appropriate methodology
- Presentation of the results.
- Discussion of the results and their significance.

I would like to sincerely thank the review committee for this year's competition: Machiel Van der Loos, Heidi Koester, Jane Huggins, Jon Gunderson, Francie Baxter, Micheal Rosen, Tariq Rahman, Cameron Riviere, Mary Rodgers, Robert Felton, Allen Hoffman, and Jan Miller Polgar. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious.

On behalf of RESNA, I wish to thank the Whitaker Foundation for its support , the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 2003 RESNA Student Scientific Paper Competition.

Richard Simpson, PhD ATP
Chair, RESNA Student Scientific Paper Competition

# EFFECTIVENESS OF REAR SUSPENSION IN REDUCING SHOCK EXPOSURE TO MANUAL WHEELCHAIR USERS DURING CURB DESCENTS

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## ABSTRACT

Recently suspension wheelchairs have been developed to reduce the negative effects of whole-body vibrations experienced by wheelchair users. This study evaluated the effectiveness of three manual suspension wheelchairs and three folding x-brace wheelchairs during curb descents of heights 50mm, 100mm, and 150mm. Data collected from a seat-plate accelerometer was used to produce raw and frequency weighted peak-to-peak accelerations. The Quickie XTR was the only chair that demonstrated shock reduction, however it shifted the frequencies of the accelerations into a high-risk range of values. Analysis of the data showed that due to the sub-optimal alignment of the suspension units during curb descents, the suspension chairs failed to perform better than standard x-brace wheelchairs in reducing shock vibrations.

## BACKGROUND

Over the course of daily activities, wheelchairs users are subjected to a variety of whole-body vibrations due to obstacles such as bumps, cracks, curb descents and uneven terrain. Extended exposure to such vibrations is known to cause rider discomfort and a variety of harmful physiological effects such as cardiovascular excitation, herniated discs, degradation of vertebrae, and chronic low back pain (2). In efforts to prevent such injuries, manufactures of manual wheelchairs have integrated rear suspension into their designs. By positioning suspension elements between the axle and the seat, they have intended to reduce the transmission of injurious vibrations to the user.

Recent studies have concluded that repeated whole-body vibrations compromise the ability of the spine and back muscles to absorb and distribute suddenly applied loads (1,3). Wheelchair users experience such quick, high magnitude loads during curb descents, thereby increasing their vulnerability to secondary spinal injuries. Recognition of this situation has resulted in recent approaches to vibration reduction.

## RESEARCH QUESTION

Though manufacturers have developed suspension wheelchairs in an effort to reduce whole-body vibrations and improve rider comfort, no data are available to assess the effectiveness of their designs. The purpose of this study was to determine whether selected manual suspension wheelchairs reduce shock vibrations transmitted to users during curb descents as compared to folding x-brace wheelchairs.

## METHODS

Six different manual wheelchairs, three rear suspension chairs (Colours Boing, Invacare A6S, and Quickie XTR) and three folding x-brace chairs (E&J Epic, Invacare Action Xtra, and Quickie 2) were used to evaluate the effectiveness of rear suspension in reducing shock transmissibility. Each chair was configured with similar critical dimensions (seat width, seat depth, backrest height, wheelbase, and camber) and fitted with similar rear wheels and casters. Rear tires on all chairs were inflated to their rated pressures and verified with a calibrated gauge. All wheelchair suspensions were set for our test pilot according to the manufacturers instructions.

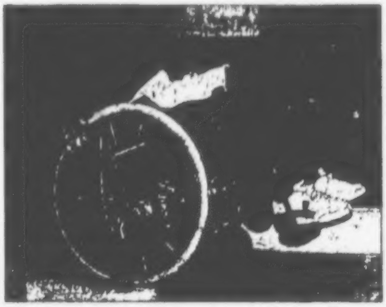

Figure 1: Descent from a 100mm curb.

The test pilot selected for this study was a male with a T7/8 level spinal cord injury, who has over twenty years of manual wheelchair experience. He was asked to descend three different height curbs (50mm, 100mm, and 150mm) with each of the six wheelchairs. The method by which the descents were made remained open to personal preference. Consequently, the test-pilot chose to perform a wheelie and then descend each curb on the rear two wheels (Figure 1). The landing area for each curb was a concrete laboratory floor. Three trials were performed for each chair, with each trial consisting of three randomized curb descents of varying height. The subject used his personal seat cushion (Vicair Academy) for each trial.

Data were collected from an instrumented seat plate, consisting of a tri-axial accelerometer fitted onto an aluminum plate, that was positioned on the seat of each wheelchair. For each set of trials, data were collected at 200 Hz, and filtered, within the accelerometer, with a 100 Hz Butterworth Low-Pass Digital filter of 2$^{nd}$ order. A Matlab program was implemented to detect the peak-to-peak accelerations and frequency weighted peak-to-peak accelerations, which emphasized component frequencies within the human oscillatory range of 4-12 Hz (4), for each curb descent. In addition, a one-way ANOVA was performed to determine the statistical difference between the two types of wheelchairs that were tested.

## RESULTS

The average resultant acceleration of each chair from each curb height was calculated and plotted (Figure 2). Both plots of mean peak-to-peak acceleration demonstrate an anticipated linear trend with respect to curb height across all chairs, with the exception of the Quickie XTR. Only after the frequency components were weighted, did the XTR display a maximum acceleration from the 150mm curb descent. The ANOVA showed no statistical difference between the suspension and folding x-brace wheelchairs in the raw accelerations (p=.645) and frequency weighted accelerations (p=.073) measured at the seat during curb descents.

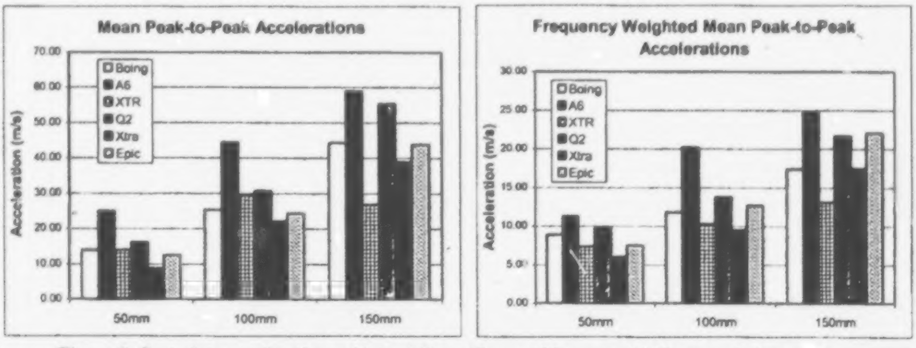

Figure 2: Seat plate accelerations obtained from 50mm, 100mm, and 150mm curb descents.

## DISCUSSION

The behavior of the accelerations shown in Figure 2 indicated that the orientation of the shock-reducing elements, imposed by the wheelie method of descent, effectively eliminated the benefits of rear suspension. The fixed alignment of the suspension units cannot adapt to, and therefore may not adequately reduce, vibrations introduced at angles that are not perpendicular to the seat pan. Therefore during activities such as curb descents, suspension wheelchairs perform more like standard, non-suspension wheelchairs.

The Quickie XTR was the only wheelchair that demonstrated a significant amount of shock reduction. During 150mm curb descents, the XTR produced noticeably smaller seat-pan accelerations. It is suspected that the magnitude of the impact force generated at this height was able to produce partial compression of the shock, thereby reducing acceleration at the seat pan. However, inspection of the frequency weighted accelerations reveal a linear trend with respect to curb height. This suggests that despite reducing impact vibrations, the swing arm suspension of the XTR shifts the frequencies of those vibrations into the range of natural frequencies of human oscillation.

## CONCLUSION

The orientation of an integrated suspension in a rigid frame wheelchair is critical in determining its effectiveness in reducing shock vibrations. In this study, the misalignment of the suspension units during curb descents negated their ability to reduce vibration. The Quickie XTR was the only chair, out of the six tested, to demonstrate effective vibration reduction. Unfortunately this process shifted the frequency of the accelerations into a potentially harmful range for wheelchair users. Therefore while suspension wheelchairs may reduce vibrations experienced during a level orientation, they did not prove effective in reducing shocks imposed during curb descents.

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# DETERMINING THE EFFECTIVENESS OF THE GAME$^{Cycle}$ SYSTEM AS AN EXERCISE DEVICE

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## ABSTRACT

The purpose of this research is to determine if the GAME$^{Cycle}$ system is an effective exercise platform and if the individual will perceive that the effort is less than if they exercised with just an arm-ergometer alone. The GAME$^{Cycle}$ system is an arm-ergometer (arm-crank) that is interfaced with a personal computer. Thirteen participants gave written informed consent before taking part in the study. The average age was 42.5 years. One trial consisted of using the GAME$^{Cycle}$ while playing Need For Speed™. The second trial consisted of spinning the arm-ergometer without gameplay. Physiologic and metabolic data was collected during both trials. After the trials the participants completed a questionnaire covering the ease of operation and if the system would help motivate them to exercise. No significant differences occurred between trials with oxygen consumption, carbon dioxide production, and heart rate. However, all were higher with game play. No significant difference occurred between groups with ratings of perceived exertion.

## BACKGROUND

The latest figures from the Centers for Disease Control estimates that disability affects nearly 54 million Americans and the cost and load to the healthcare system is great.(1) Heart disease is also the leading cause of death in the United States after the age of 25.(2) The incidence of heart disease is even greater among the disability population.(3) There is a direct correlation between physical inactivity and heart disease, the less active you are the greater the risk for heart disease.(4) There are also other detrimental physiological effects related to physical inactivity (e.g., obesity, high blood pressure, suppressed immune response.(4) The Surgeon General's recommendations in Healthy People 2000 include increasing one's activity to a level where one expends at least 1000 kilocalories per week above normal.(5) This little increase in activity can dramatically improve one's health. These recommendations however are primarily intended for unimpaired people. So, designing a program for the disabled is even more important. However, most exercise machines or devices are not designed for individuals with a lower extremity impairment and therefore these individuals have even fewer chances to exercise. The GAME$^{Cycle}$ system (figure 1), which is an interface between an arm ergometer and computer, allowing computer gameplay while exercising, could greatly improve these individuals' chances for exercising and help motivate them to exercise more often and at a greater intensity. The purpose of this research study was to determine the effectiveness of the GAME$^{Cycle}$ system to be used as an exercise device.

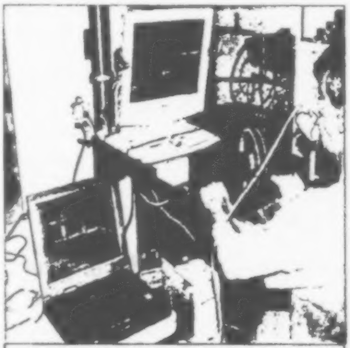

Figure 1: GAME$^{Cycle}$ system with portable metabolic cart

## RESEARCH QUESTION

*Hypothesis #1:* There is no difference in physiologic and metabolic data between the GAME$^{Cycle}$ system and an arm-ergometer.

*Hypothesis #2:* The maximum perceived exertion while using the GAME$^{Cycle}$ system will be less than the perceived exertion while using an arm-ergometer.

## METHODS

*Subjects.* Thirteen individuals with SCI volunteered to participate in this research study. The mean (± SD) age, height, weight and years of disability were 42.5 ± 9.2 years, 179.1 ± 13.2 cm, 85.6 ± 29.4 kg, 8.8 ± 6.6 years, respectively. Before participation, all individuals provided written informed consent. All participants were screened to determine eligibility before participating in the study. Participants were tested either at the Human Engineering Research Laboratories (HERL) in Pittsburgh, PA or at the National Veterans Wheelchair games held in New York City during July 2001.

*Data Collection Procedures.* Trials were performed using either an arm-ergometer or the GAME$^{Cycle}$ system. The GAME$^{Cycle}$ is an arm-ergometer interfaced with a personal computer. The interfaced, developed at the HERL, allows the user to control game-play on the screen as if using a joystick. Forward pedaling of the ergometer controls the Y-direction (up/down) and pivoting the ergometer controls the X-direction (left/right). Two trials were performed with each individual. One trial was with game-play and one trial was with the arm-ergometer and no game-play. The trials were randomized as to which was performed first. Each participant was his or her own control.

After determining eligibility, the participant was asked to sit quietly with a Polar Heart Rate monitor affixed to their chest for at least 5 minutes to determine a baseline heart rate (HR). Max HR was calculated by the formula 220 – age. From this, a range of 60% to 80% max HR was calculated. All participants were asked to pick a resistance of the arm-ergometer and cadence that would allow them to workout within this HR range for the entire exercise period of the trial. The individual selected resistance for each trial independently. If the participant went above or below the 60% - 80% max HR range they were asked to either increase/decrease cadence and/or resistance in order to maintain this range. The trial was a total of 19 minutes consisting of 2 minutes of rest, 15 minutes of exercise, and 2 minutes of cool-down. Ratings of perceived exertion (RPE) were collected every 2 minutes during the exercise phase. Metabolic data was collected using an Aerograph VO2000 portable gas analyzer interfaced with a personal computer. Data collected was oxygen consumption and carbon dioxide production. The participant was asked to wear the mouthpiece and nosepiece throughout the trial period. After the trials the participant completed a questionnaire regarding the ease of operation and if the GAME$^{Cycle}$ would help motivate them to exercise. The participant could terminate the test at any time for any reason.

*Statistical Analyses.* All data was analyzed using SPSS statistical software. Data analyzed was over the time period when steady state was reached. To find steady state, mean VO2 was calculated for all participants over the entire trial. A repeated measures ANOVA was then calculated between each point in time. The first point where no differences occurred after an initial increase in mean was used as the beginning of steady state. The last point before a significant decrease in mean was used as the end of steady state. Once steady state had been established, paired t-tests were calculated to determine if differences existed between groups with respect to VO2, VCO2, and Heart Rate data. The maximum RPE was determined for each participant and a mean calculated. A Wilcoxon signed rank test was calculated to determine significant difference between groups with respect to RPE. A p-value < 0.05 was used to determine between-group significant difference with respect to metabolic/physiologic data. Data are presented as mean and standard deviations.

## RESULTS

Of the thirteen individuals that gave written consent only twelve completed the study. That participant only completed one trial and the data was not used for statistical analysis. Table 1 lists the mean and standard deviation for the variables collected and their significance level. There was no significant difference between playing the game and not playing the game for each variable tested.

Table 1: Physiologic and Metabolic data

| | With Game | Without Game | Significance (p-value) |
|---|---|---|---|
| | Mean ± SD | | |
| VO2 (ml/kg/min) | 10.44 ± .42 | 8.99 ± .32 | 0.110 |
| VCO2 (ml/kg/min) | 9.69 ± .44 | 8.13 ± .22 | 0.455 |
| Heart Rate (beats/min) | 111 ± 3 | 105 ± 3 | 0.769 |
| RPE* | 13.5 ± 2.01 | 13.3 ± 2.42 | 0.765 |

*Wilcoxon Signed Rank Test used

## DISCUSSION

As an exercise platform, the GAME$^{Cycle}$ system is an effective means at elevating heart rate to a desired level and maintaining that level since no differences occurred between groups on all variables tested. However, the means were greater while using the system implying that with a larger sample size the differences may be greater showing that the GAMECycle is more effective as an exercise device. With its ability to increase resistance the GAME$^{Cycle}$ provides limitless adaptability as one improves their fitness level. Also, 8 of the 12 participants reported that the GAME$^{Cycle}$ would help to motivate them to exercise longer and more frequently. Techniques or tools that increase motivation will improve adherence to exercising, which is the goal of any exercise program or device. Physical inactivity or lack of exercise is associated with heart disease and physical activity has been shown to be effective in improving health status in different disease specific areas including coronary artery disease.(6) Anything that can increase the cardiac capacity may prolong the life of the individual and improve their quality of living.

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# WHEELCHAIR PROPULSION BIOMECHANICS IN PATIENTS WITH MULTIPLE SCLEROSIS

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## ABSTRACT

The objective of this study was to characterize wheelchair propulsion in individuals with multiple sclerosis (MS). A biomechanical analysis of wheelchair propulsion in this population was performed during a 1m/sec constant speed trial. Our study found that, when compared to individuals with paraplegia, individuals with MS propelled their wheelchairs at a slower velocity, despite feedback to maintain speed. In addition they produced higher propulsive forces. A quantifiable braking moment at the beginning and end of the push phase of propulsion was seen in individuals with MS. Further research should investigate ways in which clinicians can help individuals with MS become more functional manual wheelchair users.

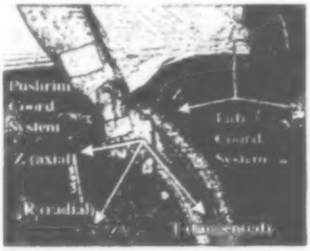
## INTRODUCTION

Multiple sclerosis (MS) is a progressive, demyelinating disease of the central nervous system. Common symptoms of MS include fatigue, weakness, and spasticity. Individuals, therefore, often rely on some type of wheeled mobility. An occupational therapist, physical therapist, or physician generally makes the recommendations regarding the type of wheeled mobility prescribed. Previous research, however, has shown that individuals with MS often present with significant functional limitations in wheelchair propulsion, not detected by clinical evaluation techniques including manual muscle testing, light touch sensation testing, and spasticity testing (1). Therefore, it is not surprising that a majority of the individuals with MS who use a manual wheelchair feel their wheelchair does not meet their mobility needs (2). The purpose of this study was to investigate the biomechanics used by individuals with multiple sclerosis during wheelchair propulsion, and to determine factors contributing to a decrease in overall functional mobility when compared to other wheelchair users.

## MATERIALS AND METHODS

13 subjects with MS and 15 subjects with spinal cord injury (SCI) participated in this study. No individuals with an upper extremity injury or cardiac condition that would limit his or her ability to propel a wheelchair were permitted to participate. All subjects gave written informed consent. Kinetic testing was performed using bilateral SMART$^{\text{Wheels}}$ (3). The SMART$^{\text{Wheel}}$ is designed to measure the 3-dimensional forces and moments about the pushrim during wheelchair propulsion (see Figure 1). Each subject used his/her own wheelchair for testing when possible. The laboratory provided a comparable wheelchair for use during testing to individuals whose wheelchairs had non quick-release wheels. Each wheelchair was secured onto a two-drum dynamometer using a 4-point securement system. Subjects

Figure 1. Lab coordinate system



were asked to propel the wheelchair at 1m/sec, using visual feedback for speed. Once subjects reached a constant speed, data were collected for twenty seconds. Actual speed and resultant force were calculated as the average of the first five strokes. Statistics were calculated using an independent t-test, with a level of significance at $p < .05$

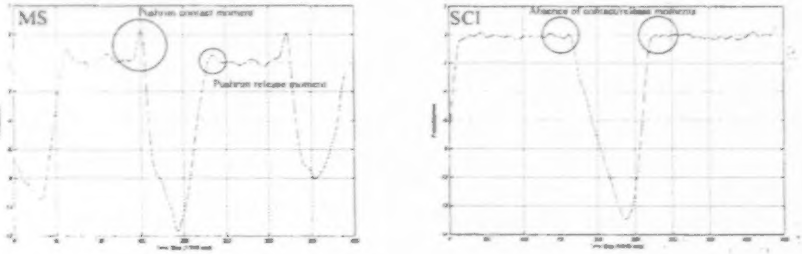
## RESULTS

Demographics: Age and number of years of wheelchair use were not significant between the two groups. Kinetic testing: Subjects with MS propelled the wheelchair slower, with a difference of 40.5% when compared to subjects with SCI (Table 1.). However, subjects with MS generated a significantly larger peak resultant force, despite their slower speeds. This indicated that considerable non-propulsive moments and forces were generated. Secondary Analysis: In a secondary analysis, we attempted to explain the apparent inconsistency between overall force produced and speed. In this, we found that a large moment in the opposite direction of wheelchair propulsion was generated. This represents a braking moment created by the individual. To quantify this braking moment we calculated the area above zero on a graph depicting the moment about the z-axis. This calculation represents the negative impulse (See Figure 2). A comparison of this measure between the two groups can be seen in Table 1.

Table 1: Comparison of speed, resultant force, and negative impulse in MS vs. SCI subjects

| *GROUP* | *SPEED* | $F_{resultant}$ *(N)* | *NEGATIVE IMPULSE* |
|---|---|---|---|
| ***MS*** | .685+/-.25 | 84.7 +/-12.0 | 59.74+/-76.288 |
| ***SCI*** | 1.033+/-.17 | 68.3 +/-21.1 | 5.0+/-3.713 |
| ***Significance*** | < .001 | Mixed model- LSD pairings: .003 | .026 |

Figure 2: Time vs. Mz in MS and control subjects



## DISCUSSION

One m/sec represents typical walking speed, and therefore, defines a functional standard for analysis. Our results show that while subjects with SCI had no difficulty achieving 1m/sec, subjects with MS were unable to attain this target speed. Furthermore, of the variables used in describing wheelchair propulsion biomechanics (4), we have found that two are important in characterizing propulsion in individuals with MS. These are resultant force and negative impulse. The resultant

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force applied by subjects with MS was significantly greater than subjects with SCI. Further analysis established that subjects with MS generated significant non-propulsive forces at the beginning and end of each stroke, as evidenced by a negative impulse. We hypothesize that individuals with MS had a difficulty grasping and releasing the pushrim during propulsion, explaining the braking moment in this phase of the cycle. This braking also helps explain the decreased speed seen in individuals with MS. These findings have important implications considering that individuals with MS are greatly limited in function secondary to fatigue issues (5). Greater energy expenditure, with a smaller propulsional output is likely to significantly restrict mobility. Further research should attempt to examine whether clinicians are able provide training which corrects for the braking moment seen during wheelchair propulsion in individuals with MS.

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# Trunk movement adaptations during wheelchair propulsion at two speeds and load conditions

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## Abstract:

The purpose of this study was to observe trunk movement adaptations when manual wheelchair users (MWUs) were faced with varying propulsion conditions. The motion of the trunk was recorded on eight MWUs using a motion analysis camera system. Three different propulsion conditions were performed: 1) slow speed, light load; 2) fast speed, light load; 3) slow speed, moderate load. The results showed that when subjects propelled at a faster speed and at a greater resistance, they adapted their trunks to lean more forward. During the faster speed condition, subjects also exhibited greater trunk range of motion. These findings may provide insight into the relationship between trunk movement and propulsion style and efficiency at a variety of conditions.

## Background:

Manual wheelchair propulsion has been recognized as a strenuous method of locomotion. Due to this characteristic, inappropriate wheelchair propulsion technique might result in overuse injuries and reduced efficiency. Studies investigating the kinematics of wheelchair propulsion have shown that large push angles and prolonged push time could increase efficiency of propulsion [1,2]. Studies have also indicated that trunk movement during propulsion might play an important role influencing performance of propulsion [3,4,5]. However, few studies have focused on trunk movement adaptations for a variety of propulsion conditions. In addition, results from previous studies on the trunk motion of racing wheelchair users cannot be generalized to non-athletic manual wheelchair users (MWUs) due to differences in the type of wheelchairs used, wheelchair setup, skill level and testing protocol. The purpose of this study was to investigate the relationship of trunk adaptations under two speeds and two resistances typically encountered in daily propulsion. Our assumption is that in order to achieve the requirement of different propulsion tasks, trunk movements will become compensatory strategies of manual wheelchair users.

## Method

*Subjects:* Eight MWUs provided informed consent to participate in this study. The subject sample consisted of five males and three females age 22 to 50 years (mean 37.6 ± 9.9 years). Seven subjects had a spinal cord injury at the T2 level and below and one subject had multiple sclerosis.

*Experiment Protocol:* The participants were tested on a wheelchair dynamometer, which was used to simulate various propulsion conditions. They were tested in their own wheelchairs and nothing about their wheelchair was altered. IRED (infrared emitting diode) markers of a three-dimensional camera system (OPTOTRAK, Northern Digital Inc.) were placed on the subject's right acromion process and wheelchair hub to identify their coordinate positions in a global frame of reference. Hip location was estimated from wheelchair measurements since markers on the hip are easily obscured by the arm and hand during propulsion. The locations of markers were recorded while the subjects assumed a resting (static) position (arms directly to the side, elbows at 90 degrees). Then, the subjects were asked to propel at the two resistances (10W and 25W) and two speeds (0.9m/s and 1.8m/s) for three-minute trials with a three-minute rest period between trials. In order to avoid potential overuse injuries and overexertion among subjects, a trial of high resistance with fast speed was not performed. The kinematic data were collected at a sampling rate of 60 Hz during the final 30 seconds of each three-minute trial.

*Data analysis:* The motion data were analyzed for excursion of the right acromion process relative to the hip in the sagittal (x,y) plane. The subjects' trunk positions during the propulsion trials were referenced to their trunk position in the resting position. The trunk angle was computed using the scalar product of two vectors: $\theta = COS^{-1}\frac{\vec{A}\bullet\vec{B}}{|\vec{A}||\vec{B}|}$

where $\theta$ = trunk flexion angle

$\vec{A}$ = vector between the hip joint and acromion process in the resting position.

$\vec{B}$ = vector between the hip joint and acromion process during propulsion.

Degree of trunk oscillation was calculated as the difference between maximum and minimum trunk flexion angle for each stroke.

*Statistical Analysis:* Maximum and minimum trunk angles and the mean range of motion were determined for each subject for each of the three conditions. Trunk values were then averaged across the first five propulsion strokes and then for the group. Since the sample size was small and data were not normally distributed, a non-parametric test ( Wilcoxon signed ranks test ) was performed for statistical analysis ( $\alpha = 0.1$ ). Means of trunk flexion and range of motion were analyzed using SPSS software (SPSS, Inc.).

## Results:

Subjects revealed significantly greater trunk flexion while propelling at a high-speed condition ($p=0.036$) (Table1). Large trunk flexion angles were also found when subjects faced a greater resistance while maintaining the same propulsion speed ($p=0.017$). During the condition of low resistance with slow speed, subjects showed the smallest degree of trunk flexion in comparison to the other two conditions (Figure1). A significant difference in trunk range of motion (ROM) was found between propulsion at the fast speed and slow speed with low resistance ($p=0.069$) (Table2).

## Discussion:

Our results indicated that MWUs leaned their trunk forward to meet the physical demands of increased load and speed. It was interesting to find that despite their physical impairment, the individuals in this study used trunk lean to adapt to demanding propulsion conditions suggesting that they have adequate volitional trunk control [5]. One reason for involving the trunk in the push could be that it increases the ability to transfer power to the pushrim and enhances the application of force to the rim[3,4]. Trunk flexion may also increase as a person approaches his/her limit on the ability to apply power.

Rodgers *et al.* found that some wheelchair users also increased their trunk range of motion as they approached a fatigue state [5]. We observed more trunk range of motion at the faster speed condition. Although we did not evaluate fatigue, this finding may provide insight into the early onset of muscle fatigue. It could also be that when the trunk is moving back and forth that this helps with generating the forces necessary for propulsion.

**Conclusion:**

Our findings indicate that MWUs use trunk movement adaptation when facing difficult propulsion conditions. Information regarding the extent of trunk movement during propulsion could be valuable in understanding the relationship between mechanical efficiency and propulsion style.

Table1. Trunk angle flexion during propulsion at various conditions

| Trunk angle (°) | Low resistance | | High resistance |
|---|---|---|---|
| | 1.8 m/s | 0.9m/s | 0.9m/s |
| Max | 14.49±6.45 | 10.73±5.82 | 12.05±5.94 |
| Min | 8.35±6.97 | 5.79±5.31 | 7.61±5.51 |
| Mean | 11.45±6.25 | 8.35±5.47 | 9.81±5.49 |
| ROM | 6.15±3.52 | 4.94±2.86 | 4.44±2.25 |

Table2. Results of statistically significant findings ($P<0.1$)

| Condition | Mean of trunk flexion | Mean of trunk ROM |
|---|---|---|
| Low resistance, fast v.s. low speed | P=0.036 | P=0.069 |
| Low speed, heavy v.s. light resistance | P=0.017 | P=0.208 |

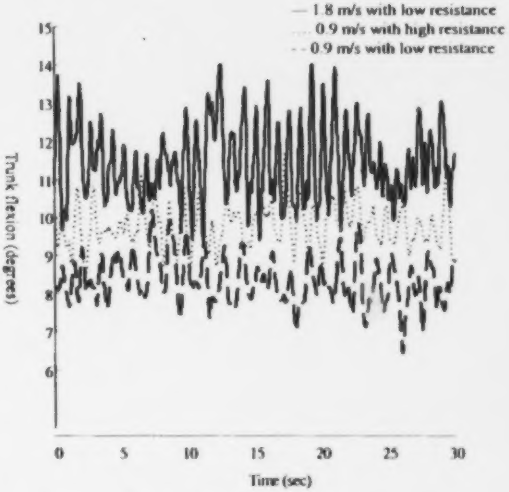

Figure1. Trunk flexion angle at various conditions. Curves represent the average trunk angle for all 8 subjects.

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# KINEMATIC STATE OF THE HAND AT IMPACT WITH THE WHEELCHAIR HANDRIM AS A FUNCTION OF HANDRIM COMPLIANCE

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## ABSTRACT

A compliant wheelchair handrim is a proposed technology that serves to reduce the risk of developing upper extremity overuse injuries. Handrim compliance was shown to reduce the rate of loading on the handrim, and for select environments, increase propulsion efficiency. The mechanism by which these results occur is not well understood and may be a result of the speed at which the user's hand impacts the handrim. Relevant propulsion kinematics and kinetics were measured during wheelchair propulsion using a rigid handrim and three compliant handrims. Hand velocity prior to impact with the handrim was not affected by handrim compliance. Hand velocity was directed radially into the handrim at an average of 0.34 m/s and tangentially was an average of 28% slower than the handrim. The lag in tangential velocity is believed allow the user to fully grip the handrim prior to advancing the hand along a constrained range of motion.

## BACKGROUND

It has been discovered that manual wheelchair users who push on the handrim with a higher rate of loading during propulsion are more likely to develop an upper extremity injury (1). A compliant handrim is a standard handrim that is elastically rather than rigidly connected to the wheel, such that it can displace relative to the wheel when impacted by the hand (Figure 1). Handrim compliance has been shown to reduce the rate of loading on the handrim during the impact phase of propulsion (2). If a reduction in rate of loading is accomplished without changes in propulsion kinematics (motion of the arm), then the reduction is due to the compliance. However, if the user tends to hit the compliant handrim with a slower hand velocity, then the resulting reduction in rate of loading is partially due to the reduced hand velocity at impact.

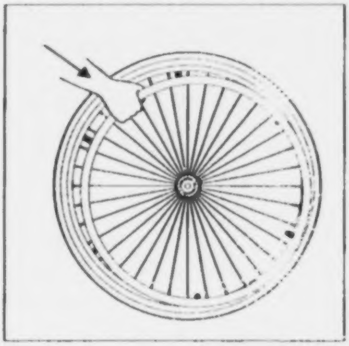

**Figure 1.** Handrim compliance allows the handrim to displace relative to the wheel when impacted by the hand during propulsion.

Handrim compliance has also been shown to preserve, and for select environments, even improve propulsion efficiency (3). It was theorized that improvements in propulsion efficiency may have been due to the user impacting the handrim at a higher velocity when using the compliant handrims. The ability of the compliant handrim to store the kinetic energy from the arm during impact and to release it to the wheel later in the push would serve to utilize energy that is normally lost at impact. Knowing the hand velocity just prior to impact with the handrim may provide valuable insight into the mechanisms that lead to improved propulsion kinetics and efficiency.

## RESEARCH QUESTION

What is the kinematic state of the hand just prior to impact, and is it affected by changes in handrim compliance?

## METHODS

Five experienced manual wheelchair users gave written consent and participated in the study. Subjects propelled their wheelchairs on a dynamometer at 1.3 m/s (3 mph) using a rigid handrim and three compliant handrims. The compliant handrims, Min, Max, and Max-R, described previously (2), represent minimal compliance, maximal compliance, and maximal rotational compliance, respectively. The dynamometer resistance was set to simulate propelling up a 2% (1:50) grade. Pushrim kinetics and wheel angular position were measured using a SMART$^{Wheel}$ (Three River Holdings) mounted on the subject's wheelchair. Propulsion kinematics were measured using an optical marker tracking system (Optotrak). Markers were placed on the 3rd metacarpal and the wheel. Subjects propelled for 20 seconds and the data was filtered using a 4th order Butterworth filter. The kinematic and kinetic data collection systems were triggered to ensure the timing was synchronous. The first 10 pushes were used in the analysis.

Hand velocity was determined by numerically differentiating the three-dimensional hand position coordinates over the trial. A non-zero load applied to the handrim identified the start of a push. The hub of the wheel was defined as the average location of the wheel marker. A line connecting the hub of the wheel to the hand marker was used to determine contact angle. Propulsion and handrim velocities were determined by multiplying the angular velocity of the wheel by the wheel and handrim radii, respectively. The hand velocity vector was transformed from an inertial frame of reference to a wheel-fixed reference frame through a rotation equal to the contact angle. The resulting hand velocity components are radial, tangential, and lateral with respect to the wheel. The ratio of the tangential hand velocity to the handrim velocity was calculated. Results for each subject were averaged over the ten pushes to form a single characteristic value. The results for each compliant handrim were compared to those of the rigid handrim using a two-tailed paired samples t-test and considered to be statistically significant for $p<0.05$.

## RESULTS

The resulting hand position at impact and velocity just prior to impact are listed in Table 1. Both hand position and velocity are described relative to the handrim. Propulsion speed was not found to differ statistically between the rigid handrim trials and the compliant handrim trials. Neither hand position nor velocity differed statistically between the rigid handrim trials and the compliant handrim trials.

**Table 1.** Hand position and velocity just prior to impact with the handrim (Average (SD)).

| Handrim | Propulsion Speed (m/s) | Contact Angle (deg) | Hand Velocity (m/s) | Radial Hand Velocity (m/s) | Tangential Hand Velocity (m/s) | Lateral Hand Velocity (m/s) | Tangential Hand Velocity Ratio |
|---|---|---|---|---|---|---|---|
| Rigid | 1.28<br>(0.23) | -21<br>(8) | 0.90<br>(0.20) | 0.34<br>(0.13) | 0.80<br>(0.23) | 0.00<br>(0.09) | 0.72<br>(0.06) |
| Min | 1.30<br>(0.15) | -18<br>(7) | 0.84<br>(0.14) | 0.32<br>(0.08) | 0.78<br>(0.20) | 0.00<br>(0.06) | 0.67<br>(0.15) |
| Max | 1.22<br>(0.25) | -21<br>(12) | 0.88<br>(0.28) | 0.38<br>(0.15) | 0.76<br>(0.32) | 0.02<br>(0.10) | 0.70<br>(0.15) |
| Max-R | 1.29<br>(0.18) | -24<br>(7) | 0.89<br>(0.16) | 0.33<br>(0.10) | 0.80<br>(0.20) | 0.02<br>(0.08) | 0.73<br>(0.08) |

## DISCUSSION

Hand position and velocity prior to impacting the handrim were not affected by handrim compliance. These results indicate that reductions in the rate of loading of the handrim when using a complaint handrim are due to compliance characteristics and not the result of a slower hand velocity. Additionally, any improvements in propulsion efficiency are due to factors other than an increased hand velocity.

Perhaps most informative are the hand velocity characteristics across all the handrims. The radial component of hand velocity indicates that the hand is being driven into the handrim in a direction the handrim does not move. The lateral component of hand velocity indicates that there is little or no relative lateral movement at impact. The tangential component of hand velocity for this propulsion speed is approximately twice that of the radial component. The tangential hand velocity ratio indicates that the hand is moving slower than the handrim at impact. These results help explain why the radial component of force on the handrim exhibits an impact spike while the tangential component is initially in the reverse direction, resulting in a negative torque on the wheel (Figure 2). Boninger et al. found similar kinetic characteristics for propulsion at 2 and 4 mph on a simulated level surface (4). It is believed that tangential hand velocity lag serves to allow the user to fully grip the handrim prior to advancing the hand along the push arc, thus utilizing a full range of motion on the handrim.

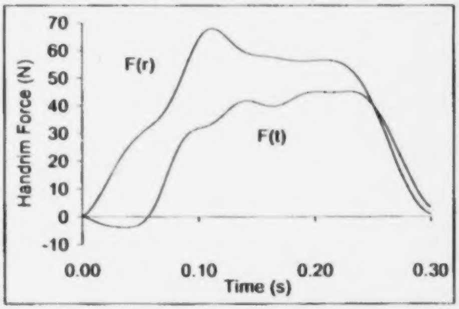

**Figure 2.** Handrim force profile measured for one subject. Radial force component, F(r) has a characteristic impact spike. Tangential force component, F(t) has a characteristic reverse direction at the beginning of the push.

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# RESNA Student Design Competition

## RESNA Student Design Competition

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The RESNA 2002 Student Design Competition recognizes the exemplary work of 5 student teams in the field of Assistive Technology. This year, a total of 20 entries were submitted, from student teams reflecting the interdisciplinary profile of the field.

Designs were judged with respect to the following criteria:

- Appropriateness with respect to real user needs
- Input from intended users or manufacturers
- Innovation and creativity
- Manufacturability and market potential
- Cost to end-user
- Technical competence
- Documentation
- Working prototype or model

All award winners have brought their designs to the Conference for your review. Please visit the Student Design Competition display, and try out their devices.

Continued thanks are in order for the support provided by the Independence Technologies, a Johnson & Johnson Company. Through this strong support, Independence Technologies encourages student design efforts in the area of Assistive Technology. RESNA expresses thanks to Vice President for Marketing Dave Brown for making this possible.

RESNA's Susan Leone provided the extensive support necessary for the Student Design Competition to run smoothly. As always, her efforts were very much appreciated.

The difficult process of analyzing the designs was carried out with skill by an interdisciplinary panel, who generously devoted the time essential for a thorough and fair review. The panel includes consumer, therapy, engineering, and manufacturing perspectives. RESNA is very appreciative of their efforts.

Thanks go out to all students who submitted entries. Choosing five designs for this year's award was a difficult task.

Glenn Hedman, PE, ATP
Chair, Student Design Competition

# DEVELOPMENT AND EVALUATION OF A THORACIC PRESSURE CHAIR FOR A STUDENT WITH AUTISM

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## ABSTRACT

Pressure therapy has been demonstrated to lower anxiety levels in children with autism (3,4). A therapeutic thoracic pressure chair (TPC) was developed for a 13 year-old male student with autism. The chair is user-controlled and capable of generating and sustaining forces to the chest ranging from 0-90 lbs. It has several unique characteristics that make it safe and welcoming to the student as well as potentially advantageous over a commercially available design. The TPC was placed in the student's classroom with unrestricted access. The student uses the device daily and preliminary results indicate that chair use has lowered the student's anxiety level.

## BACKGROUND

Autism is a complex neurological disorder that currently has no cure. Onset occurs in infancy or early childhood with a median prevalence rate of 7.2/10,000 people (1). Autism is identifiable by several profound deficits that include: difficulty with social communication and sensory processing, self-removal from the surrounding learning environment, an obsession with repetitious routines, and high levels of arousal or anxiety (2). Several interventions have been employed to circumvent these symptoms including various drug and vitamin treatments, auditory integration therapy, and somatosensory activities (3). One particular form of somatosensory activity, deep pressure therapy, is often used on individuals with autism.

Temple Grandin, an individual with autism, has developed a device called a Squeeze Machine (4). It functions by delivering deep lateral pressure to the body via a system of pneumatic valves and padded platforms. One clinical study found that this machine was able to lower arousal levels in children (4). However, the device is costly ($4,375), heavy (350 lbs) and large (68 $ft^3$) (Therafin Corp., Mokena, IL). This limits its utility and availability in a classroom setting.

## PROBLEM STATEMENT

The design challenge was to build a user-controlled thoracic pressure machine for a 13 year-old male with autism to assist with control of anxiety and perception of external environment.

## RATIONALE

Several somatosensory therapies were given to the student daily including stroking of the hair and shoulders, delivery of impact forces to the chest (created by the teacher's palms), and occasionally, sandwiching the student between two beanbags. Although these therapies seemed to lower the student's anxiety levels, the student could not control the frequency or intensity of these treatments. Furthermore, the student had an apparent desire for deeper chest pressure that could not be administered by his teachers. Therefore, it was critical to design and develop a user-controlled thoracic pressure device capable of creating and sustaining deep pressure.

## DESIGN PHASE

The design objectives were the following: simple to use, unobtrusive in the classroom, require AC power, user controlled pressure, aesthetically pleasing, distribute pressure from the naval to shoulders, and safety. The design was constrained by the following: total material cost under $900, distribute less than 100 lbs of force, and weigh less than 150 lbs.

## DESCRIPTION OF PROTOTYPE

The TPC was created conforming to the design objectives and constraints (Figure 1). The chair operates as follows:

The user sits in the chair and closes the padded door. The user places both arms to his sides and locates two push buttons (one for each hand). The two push buttons are pressed and held at the same time to commence motor power and inward movement of the pressure platform. Once the platform creates the desired pressure level (which takes up to ten seconds) the user releases one or both of the buttons. The platform will remain in the stopped position, providing pressure to the chest. If more pressure is desired, the user can press the power buttons again. To leave the device, the user pulls on a lever located near his right hand. While the lever is continuously pulled, a gas spring pushes the platform away from the chest. Finally, at its starting position, the door, which is no longer under pressure, automatically opens via an automatic latch.

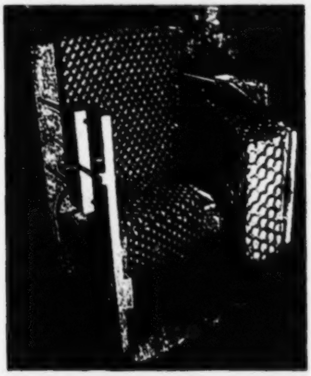

Figure 1- Frontal View of the pressure chair

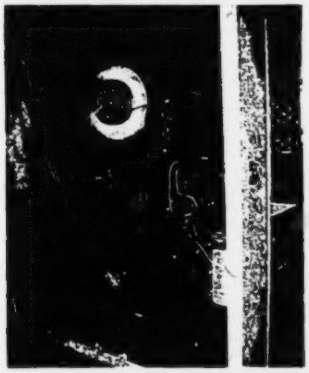

Figure 2- Working components of the pressure chair

The working components of the TPC consisted of a number of electrical and mechanical parts (Figure 2). The motor is a 1/3 HP, 1750 RPM, AC motor (Series A Radicon, Texatron Power Transmission, Traverse City, MI). A separate worm-gear unit was used to decrease the motor speed and prevent loss of pressure when the motor power was cut (WEG, Texatron Power Transmission, Traverse City, MI). The motor drives a v-belt that rotates a system of two pulleys. A single length of aircraft wire is connected to the two ends of the pressure platform and pulley. When the motor is turned on the v-belt rotates the pulley system, winds the wire around the pulley and causes the pressure platform to ride along four guide rods and move toward the user's chest. A belt tensiometer creates the belt pressure necessary to drive the system. When the tensiometer is removed from the motor v-belt system, using the release lever, the pulleys backspin and the wire is unwound from the pulley. With the aid of a gas spring, the platform is guided away from the user's chest, platform pressure is relieved, and the door automatically opens at its starting position.

Several mechanisms were developed to ensure that the thoracic pressure chair was safe to operate. Two rotational limit switches were strategically placed near the pulleys to prevent excessive chest pressure and prohibit the door from automatically opening while pressure was applied. Also, an adjustable circuit was developed to limit chest forces to 0-90 lbs. In an emergency situation, a manual door handle can be used to open the pressure platform even while pressure is applied.

## EVALUATION

At a six-month follow-up the teachers reported that the student uses the chair at least once a day. The student is capable of understanding when pressure therapy may be necessary. He shows a picture book to his teachers to communicate his desire to use the chair. The teachers are satisfied, stating that the student appears to have lower anxiety levels and is now able to control his external environment by using the TPC when he deems it necessary.

Several design aspects of the chair suggest that it is an effective, and cost efficient design that could be useful to a range of persons with autism. First, the device was easy to manufacture. None of the prototype components required precision machining. Furthermore, the total weight of the chair is less than 100 lbs. and the material cost was just over $900. The chair's controls are easily located and provide user controlled pressure while ensuring safety. Finally, preliminary results indicate that this device may be a useful tool to combat high anxiety levels exhibited by persons with autism.

## CONCLUSION

The challenge of this design project was to build a device conforming to the needs of one student with autism. Based on teacher feedback and student use, we believe that the thoracic pressure chair has been a valuable rehabilitation technology system for this student. Furthermore, we are optimistic that others who exhibit similar symptoms and characteristics of autism could use the TPC. Future studies are necessary to objectively evaluate the clinical efficacy of the device.

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# An Assistive Bowling Device for Persons with Disabilities

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## ABSTRACT

Involvement of people with disabilities in recreational activities is important to ensure their physical and mental well being and a smooth inclusion into society. At Rosedale school in Austin, students with disabilities like to bowl. However, with the current device – a bowling ramp - the ball has to be pushed by hand in order to launch it. The speed of the ball leaving the ramp is very low and the ramp also cannot accommodate different wheelchair sizes.

The team designed, developed and prototyped a device that accelerates the ball to a speed equivalent to that of an able bowler, accommodates different sizes of wheelchairs, and can be used independently by children with limited motor capabilities. The device also provides causal, visual, and auditory feedback. It is modular, elegant and portable.

## BACKGROUND

The Rosedale school in Austin has students with cerebral palsy, mental retardation, autism and severe motor disabilities. The school strives to provide skills to these students, necessary for them to lead independent lives. An important part of the curriculum is the inclusion and learning of recreational activities. In addition, recreational activities help the children improve their motor capabilities and response to different sensory stimuli. Bowling is one such activity. The students bowl in the school gymnasium regularly and go to bowling alleys every week.

## STATEMENT OF THE PROBLEM

The existing bowling device presents certain limitations. The ball rolls down with a velocity of 5 miles/hr, whereas, the average person can bowl at 12-15 miles/hr. Most children find it difficult to launch the ball, as their wheelchairs cannot slide under the ramp. Children with limited motor capabilities cannot use the device, and the device is not portable.

Based on these limitations, our goal was to design, develop and prototype a device that was easy to use for all the children and provides a ball speed of about 10 miles/hour. In addition, the device had to accept a variety of feedback devices, which could be modularly attached to the device based on user preference and need.

## CUSTOMER NEEDS ANALYSIS AND CONCEPT GENERATION

Interviews were conducted to extract and understand the customer needs. Latent customer needs were uncovered, which gave the design team new directions for product development. The Semantic Inquiry method was used during interviews to capture the product feel and industrial design attributes desired. The QFD (Quality Function Deployment) methodology was used to translate customer needs into engineering metrics. Important relationships and dependencies were represented in the House of Quality matrix. We were able to check for conflicts between engineering requirements like the length of the ball acceleration module and that of the ramp. Target specifications were established for the ball speed (10–12 miles/hr.) and the range of device heights (28"-33"). With these specifications, the team moved into the concept generation phase. Functional decomposition and modeling techniques (2) were used to establish product functions and identify modules. The 6-3-5 and memory mapping techniques were used extensively to generate a breadth of solutions for every function. These solutions were combined using the morphological matrix to form concept variants. The concept variants were ranked against each other using the metrics drawn from the QFD matrix. For example, some of the concepts for holding and launching the ball were a spring-loaded pusher, an electrically actuated solenoid pusher, a motor-driven Geneva wheel, and a tilting platform. The solenoid pusher was chosen based on the reliability, ease of fabrication and weight metrics from the QFD matrix.

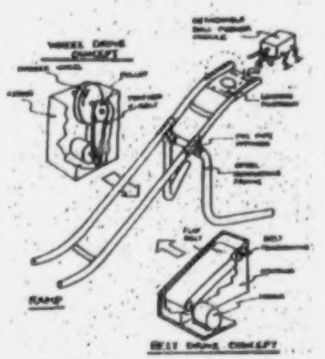

*Figure 1: The proof-of-concept Prototype for the selected concept variant*

**DESIGN AND DEVELOPMENT**

Two proof-of-concept prototypes were evaluated: a belt drive and a rubber wheel drive concept. The team also sought to find the optimum position of the acceleration module with respect to the ramp. Results showed that the belt drive did not accelerate the ball any more than the wheel did. The greater the differential velocity between the ball and the wheel/belt, the greater was the final ball speed. The prototype also helped the team in understanding the relationship between the instantaneous centers of rotation of the ball and the wheel (the projection of the wheel above the ramp) and the final ball speed. Based on the results, the team chose the wheel drive concept.

An alpha prototype was designed and built on this concept. It constituted the three main modules of the device: a ramp with adjustable height, a loading platform and device feedback module, and a ball acceleration module. The main challenge in designing the ramp was making it sturdy, portable and independent of the acceleration module. Polished and buffed stainless steel tubes were used for their strength and elegance. Manufacturability constraints forced the team to keep the steel structure simple and yet functional. Stability of the ramp was another concern. The acceleration module could not be used to support the ramp, hence necessitating a supporting frame. The complex steel frame in the proof-of-concept prototype (see figure 1) was subsequently replaced by a U-frame that was not only easy to fabricate but eliminated the problem of sustaining cantilever loads. The ramp rests on collapsible wooden frame. The entire frame and the outer steel tube fold into a compact structure that can be carried. Device height adjustment is provided by the telescopic construction of the ramp and is simple to operate.

The loading platform holds the ball before launching it and subsequently guides it onto the ramp. The ball-pusher module was integrated into the loading platform. This provided greater access to the ball and facilitated function sharing (figure 2). This module is compact, safe and provides two different feedbacks to the user. The first feedback signals that the ball has been loaded. The ball can either be pushed down the ramp by hand or in the case of children with limited motor capabilities, it can be launched with a solenoid plunger actuated by a Big Red™ switch mounted close to their head or elbow. The second feedback device consists of rope lights running down the length of the ramp. The lights turn on as soon as the ball has left the loading platform and are controlled by a timer circuit. The plunger prevents the ball from rolling back towards the user. There is a safety feature in the module that prevents accidental actuation of the solenoid plunger if the ball has not been loaded or is improperly loaded.

The acceleration module beta prototype features a direct drive to the wheel, which is a significant improvement over the alpha's belt-driven wheel. Some of the issues that dictated this decision were reliability, efficiency, cost and weight. Among other concerns was the vibration isolation of the acceleration module. Mounting the wheel on bearings on both sides and adding balancing weights to the wheel rim eliminated this. This module consists of a concealed 0.3 hp motor directly driving a 10" rubber wheel at 1075 rpm in the opposite direction as that of the ball rotation. When the ball comes in contact with the wheel, rotational energy is transferred to the ball and when the two have equal spin, the ball climbs over the wheel and rolls down the ramp at a speed of about 11 miles/hour.

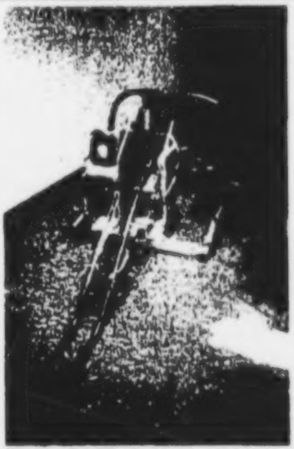

*Figure 2 : The beta prototype*

## DESIGN EVALUATION

The teachers and students at Rosedale are very excited about the device. They find the height adjustment easy to use. The children love the feel of steel. At times during the game they grab the ramp in excitement. This is safe due to the ramp's robust design and smooth curves. The ramp can accommodate all the wheelchair sizes at Rosedale. The teachers can conveniently fit the entire device in their car trunk when they take the children to the bowling alley. The ramp can be stored in a corner of the gym at the school. The acceleration module can be easily moved on its rollers and slid into position under the ramp.

The children love the lights on the device and the teachers dubbed it as a 'Wow!' factor. They say that the user's attention gets directed to the ball as it leaves the ramp and this keeps them interested in the game for longer. They also love to watch the ball as it spins over the wheel, climbs over it and rolls down the ramp.

## ACKNOWLEDGEMENTS

We would like to thank our professors Dr. Kristin Wood and Dr. Richard Crawford for encouraging us and providing technical guidance and training throughout this project. We are also grateful to Ms. Dedra Standish and Ms. Mona McCullough at the Rosedale school for their support and help.

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# MAGIC TIMER: A Multi-sensory Assitive Innovation

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## ABSTRACT:

Conceptualizing, visualizing and understanding the passage of time are difficult concepts. The concepts are even more difficult for people with cognitive and sensory related disabilities. Assistive technology can help people with disabilities understand the concept of time. Understanding these concepts allow people with disabilities to take steps toward achieving greater independence. The development of a timing device that can be used by people with a variety of sensory related limitations should remove barriers and enhance the ability of those people to function in the greater society. This paper discusses the development of such a multi-sensory timer by our student team. The team developed the timer based on customer needs to provide visual, tactile, and auditory feedback. The device was developed for a specific group of autistic children but will provide utility to a broad range of people with sensory disabilities.

## BACKGROUND AND PROBLEM STATEMENT

The Rosedale School in Austin, TX is a school for students with special needs that provides the teaching and training of life skills. One classroom used kitchen timers and the Time Timer [1] to assist students' development of the understanding of how long they needed to do various activities. These activities included basic life skills like eating, and work skills such as stamping envelopes and preparing product promotion materials. The teacher and teaching assistants used timers throughout the day for numerous activities. These timers included an hourglass sand timer, kitchen timers, and the Time Timer. The timers were not eliciting the desired response from the students. Additionally, the existing timers had to be observed to determine the time remaining and, excluding the ding or buzz of the kitchen timer, did not signal the end of a timed period.

Our customer wanted a timer similar to the Time Timer, which provided a large visual dial to show the passage of time, but with a better indication of the expiration of the timed period. The existing timers could not fulfill these requirements so he sought development of an improved timing device with better sensory cues. Because every student reacts to different stimuli, he sought the ability to tailor the sensory output to best meet the needs of the individual being timed. Thus, the problem was to develop a product with a multiple means of indicating the passage of time periods and multiple methods of indicating the end of a timed period.

## DESIGN AND DEVELOPMENT

The project team used the product design and development methodology as outlined by Otto and Wood[2]. This started with task clarification and customer needs identification. The following steps were customer needs analysis, functional modeling, Quality Function Deployment, concept generation, concept selection and prototyping. During the initial phases of the project, the team engaged in various team-building activities to enhance the effectiveness and relationships of its multicultural members[2,3].

### Phase I: Customer Needs Identification and Analysis

The team conducted interviews with the teacher, teaching assistants, parents, and the school's occupational therapist to better understand the problem and customer. This resulted in a list of customer needs and mission statement that included product description, goals, market, assumptions, stakeholders, and limitations.

Phase II: From Functional modeling to Concept selection

Customer needs were translated into functional models and engineering specifications to provide a Quality Function Deployment (QFD) matrix. The functional models and QFD provided context for concept generation activities. Concept generation involved individual work, brain-mapping and 6-3-5 techniques[2]. Various modules and models were built for proof of concept and customer feedback. The feedback resulted in the selection of colors, sensory signals, and a visual indicator similar to the Time Timer, since students were familiar with the dial and face[1,4]. The various concepts were further evaluated and refined using Pugh Charts. The goal was to use off-the-shelf components that are easy to procure and relatively low cost to provide an economical and reproducible design.

Phase III: Prototyping

A circuit that incorporated customer needs was built into an existing timer case as a prototype. It had a main switch and LEDs on the front and control switches on the rear. This prototype was well received by our customer. The size, color and vibrations functions were particularly appreciated. Suggestions for volume control on the voice module and the ticking sound were requested, as well as brighter lights and additional tactile output from a blower. The prototype was taken to another school, where two teachers suggested: Hiding the switches to avoid manipulation by kids and placing the lights on top of the timer to be view from all directions. These ideas were included in the next design.

Figure 1. Alpha Prototype

A computer aided design (CAD) model that incorporated original customer needs and those restated needs based upon the Alpha Prototype was developed. A casing for the Beta Prototype was made using rapid prototyping equipment available at the engineering school. Other than the custom casing, this prototype was again made completely with off-the-shelf components.

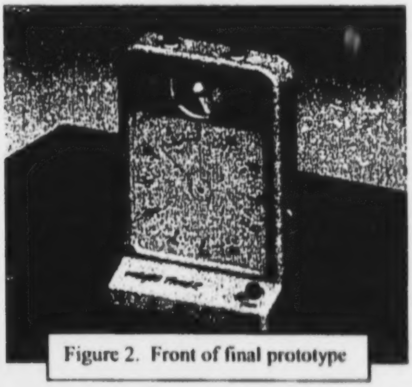

Figure 2. Front of final prototype

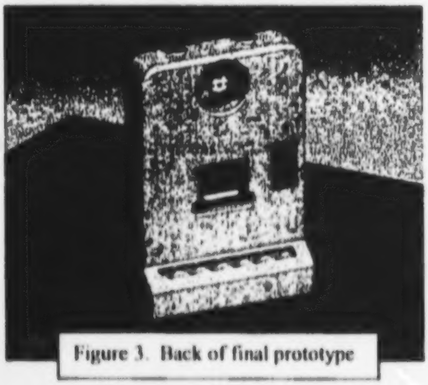

Figure 3. Back of final prototype

**KEY FEATURES OF MAGIC TIMER:**

1. Simple push button on/off switch and LED on face indicating if magic timer is on/off.
2. Six sensory cues: buzzer, pre-recorded message, ticking sound, blower, vibrations, lights.

3. All signals can be used during the passage of time or at the end of time period set.
4. Time timer can be activated alone without using any sensory cues.
5. A personalized recordable 20-second message feature.
6. Volume control for ticking sound and pre-recorded message.

## DISCUSSION AND DESIGN EVALUATION

The teacher and students at Rosedale School successfully used the final version of the Magic Timer for their activities. Responses to the timer varied. Tawnya and Iasia responded to voice and fan modules very well. Nick responded better to the voice and lights. Jon was not very responsive to the new timer and needed further assistance from his teacher. Rod was impressed by the Magic Timer and the response his students demonstrated. While the timer was developed as an individual timer, group activities for the classroom can be moderated using the lights and volume control.

Outside of our targeted classroom, occupational therapists and teachers from the Westlake School felt that a multidimensional timer would be an excellent tool for people with cognitive and sensory disabilities to time their daily routine activities. Our team agrees, but still feels that the product has room for improvement. For instance, incorporation of a jack to plug in external toys or other devices was suggested. The design could be modified for this so a sensory output could go to a remote position. Also, improvements could be made to the end of time sensor. Additionally, we feel the power consumption would be better controlled in a mass produced product.

A version of the Magic Timer can be assembled using purchased components for about $120 excluding labor. If a single custom case is used, the components are under $100, but the case is expensive. On the other hand, a mass produced injection molded case and components purchased in volume would allow the timer to be sold for under $50. The existing Time Timer currently sells for $25.

A broad scope of input has allowed us to create a product that meets the needs of our specifically identified customer, but also serve the larger needs of people with sensory limitations. We have provided a working timer which has satisfactorily met the requirements of many people who assistance with understanding time passage and knowing when a time period has ended.

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# INFANT PATTING DEVICE

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## ABSTRACT

Infants in the neonatal intensive care unit (NICU) must be calm in order to feed properly. One person is needed to calm the infant using a patting motion, while another person swaddles them in a blanket and holds the bottle. This requirement can strain the professional staff in an intensive care setting. A device was built that allows a single nurse to manage all feeding tasks in a safe and timely manner. This device uses the pressurized air source available in the hospital to inflate a bladder, which provides a patting motion. A pressure limiter and an electronic solenoid valve regulate the inflation of the bladder. With minor modifications, the device can become portable for home use.

## BACKGROUND AND PROBLEM STATEMENT

A Speech-Language Pathologist specializing in swallowing mechanics works with infants in the neonatal intensive care unit (NICU). She requested a device that would provide a patting motion to an infant during bottle feedings in the NICU. Currently, caregivers use a hand patting motion to calm the baby so he or she will accept the bottle for feeding. The patting motion may help prevent the aspiration of food into the lungs. Aspiration can lead to serious complications in what is already a health-compromised population. The problem with hand patting is that it takes two hands to feed and another to pat. This cannot be done by one person. An inflatable bladder was chosen to deliver the patting motion because it completely isolates the baby from the electronics and there is an in-house air source in the NICU. The electrical isolation is important because safety is absolutely the most important requirement of the device. The device must also be effective and easy to operate in order to get used by the NICU staff with any regularity.

## DESIGN AND DEVELOPMENT

### *General Approaches and Design Selection*

Several approaches to the system design were investigated. First, a closed-system was considered that consisted of two inflatable bladders connected by a hose. Stepping on one bladder would inflate the other bladder that would pat the infant. The disadvantage of this system is that it operates under user power. Therefore, we did not choose this approach because of the unreasonable user effort required for a 40-minute feeding. Second, a purely pneumatic system was considered that would make use of the air supply and deliver controlled puffs of air at a variable rate. Pneumatic controls probably exist that could create this effect, however the authors could not guarantee that this design would be completed within the timeframe of the project. Therefore, a third design approach of using both pressurized air and electrical components was adopted.

### *Mechanical Function*

The first phase of the project was to verify that puffs of air with acceptable force could be delivered using the NICU air source. It was determined that the maximum pressure needed from the air source to produce enough patting force was about 25 psi. This was well below the 60 to

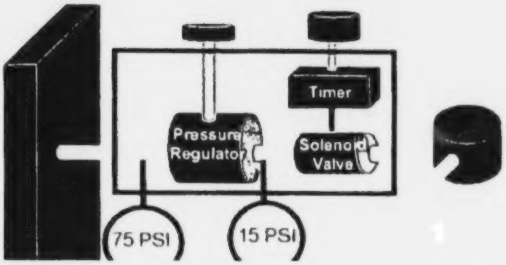

**Figure 1: Basic Design**

85 psi that was available in the NICU. With an ample source of air, a valve system was constructed that converts the steady source of high-pressure air into intermittent puffs of air (Figure 1). The pneumatic components in this system were interconnected with ½" diameter hose, which was large enough so that airflow was not impeded.

Air comes from the NICU source and enters the manually adjustable pressure regulator. Our pressure regulator is able to handle input air pressure up to 200 psi and an output pressure from 2-60 psi. This provides the correct force for patting, but outputs a steady flow. To get the intermittent puffs needed for patting, we used a solenoid valve. The solenoid valve is an electrically controlled valve that is normally closed but opens when 24 V DC is applied. The solenoid selected has a large 5/8" aperture to maximize airflow. A solenoid that operates on 24 V DC was chosen because it has the lowest power requirement and could be run off of a standard, commercially available 24V plug-in power supply. The solenoid valve outputs the desired puffs of air when switched on and off. A timer circuit (described in the next section) provides an electrical signal to control the solenoid, and the user can adjust its frequency.

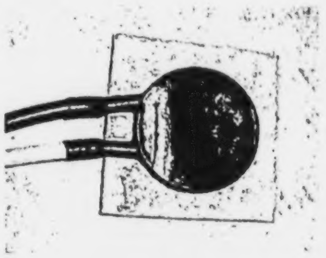

**Figure 2: Custom Bladder**

To convert the puffs of air to a patting motion, a custom, inflatable bladder was designed. The bladder is pancake-shaped with a 3½-inch diameter, approximately the size of a small infant's back (Figure 2). It has an input line that is connected to the solenoid and an output line that is a few feet long and open on the other end.

When the solenoid valve opens, it delivers a puff of air to the bladder; then, the bladder expands, delivering a pat. The air quickly rushes out of the bladder down the output hose. The several feet of hose on the output line are secured to the input line and are designed to take the air away from the infant. Due to latex allergy concerns, the bladder was constructed of neoprene.

### *Circuitry*

A custom circuit system was designed to trigger the solenoid. The whole electronic system can be turned off and on by a power switch. Since the solenoid runs on 24 V DC, that is the only input to the circuit. A 24 V DC to 5 V DC voltage regulator is used to deliver 5 V to a 556 timer circuit. The timer circuit delivers a 15 ms pulse of 5 V at a frequency that is dependent on a potentiometer. The potentiometer is controlled by a knob accessible to the user to allow adjustment of patting frequency. The 5 V pulses are sent to the gate of a power MOSFET. The gate, when open, connects the solenoid valve to ground. The other pin on the solenoid is connected to the 24 V source, so the valve is open during the timer pulses only, delivering the puffs of air.

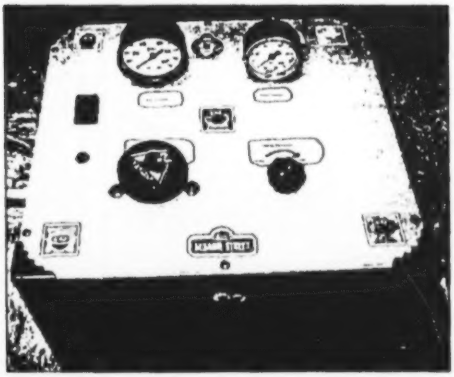

Figure 3: Project Box

*Aesthetics*

All parts of the device except the bladder are housed in an aluminum project box (Figure 3). The box has the input hose and power supply on one side and the output hose to the bladder on the other side. This is designed to separate the moving parts and electronics from the infant and caregiver. The top of the box includes the pressure and frequency adjustment knobs and an on/off switch with an LED indicator. Finally, the box is covered with Sesame Street® stickers and mounted on wheels for portability. 25ft of hose allows nurses to sit, stand, and move around during use.

## EVALUATION

The initial device evaluation consisted of a presentation to an audience of occupational therapists, physical therapists, speech-language pathologists, and biomedical engineers. A demonstration followed in which people operated the device and provided feedback and suggestions. Currently, the device is awaiting approval to be used in a clinical setting.

## DISCUSSION AND CONCLUSIONS

The device works well and as intended. It delivers pats to the infant that are comparable in force and frequency to those delivered by a NICU clinician. The only questionable element is that of the bladder support. It has yet to be determined whether the bladder will go directly against the baby or in some kind of brace. Foam pads with bladder size cutouts have been purchased and seem to provide a good support for the bladder. Several people at the demonstration pointed out that a disposable glove could be used over the bladder if it went directly on the back of the infant. Although acoustic noise was an initial concern, the bladder design and the isolation of the valve from the user make it relatively quiet.

## ACKNOWLEDGEMENTS

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# CUSTOM WALKER WITH ROTATIONAL HIP SUPPORT

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Duke University

## ABSTRACT

The goal of our project was to provide a custom walker for a 6-year-old girl that she can use for both gait training and quotidian ambulation. Our client has athetoid Cerebral Palsy, which causes a lack of voluntary muscle control; therefore, she is unable to walk without the aid of a walker. Unfortunately, she has outgrown her current walker, and no commercial walkers fit her specialized needs. We therefore developed a custom walker with a rotational hip support, sling seat, and armrests that can accommodate her narrow shoulders. The walker facilitates increased mobility and independence and will play an important role in our client's goal to walk without the aid of a walker some day.

## BACKGROUND

Our client is a six-year-old girl with athetoid Cerebral Palsy. This type of cerebral palsy is characterized by fluctuations in muscle tone that are either too tight or too loose. People who have athetoid Cerebral Palsy often exhibit uncontrolled movements that are either slow and writhing or rapid and jerky, like our client [1].

Our client has outgrown her Gator reverse walker by Snugseat, and after much research we determined that there isn't a commercial walker available that meets her present needs. Our client is unique in that she is very tall and thin at 48 inches and 40 lbs. This poses a problem because most of the walkers that are available for her height are too bulky and cumbersome for her to easily maneuver. In addition, the armrests on most walkers are too wide; thus, she is unable to use them. Our client's physical therapist also requested a feature that is currently unavailable on the commercial market: a hip support that could rotate and fix our client's hips in a position that improves her gait. Furthermore, the client personally requested that the walker have a sling seat that she could use when she gets tired of standing.

## PROBLEM STATEMENT

The goal of this project was to provide our client with a walker and hip support that will fit her current and future needs. To accomplish this, the walker had to be adjustable to grow as she grows. It had to be light and easy to maneuver. It needed a hip support that could be rotated and fixed into place. The walker also had to have an easily removable sling seat. Finally, the walker needed the ability to be used both indoors and outdoors.

## RATIONALE

The purpose of our walker is to help our client with gait training, daily ambulation, and increased mobility. She is still learning how to walk, and so the walker will aid her in her therapy sessions. It is also the hope of our client's parents and therapist that she will use the walker at school instead of the wheelchair that she is currently using. The increased activity will help strengthen the muscles in her legs. In addition, the walker will give our client a greater range of mobility. The large tires on the walker will allow her to traverse terrains such as grass that she was unable to navigate before, thus enabling her to attend activities such as her brother's soccer games.

## DESIGN AND DEVELOPMENT

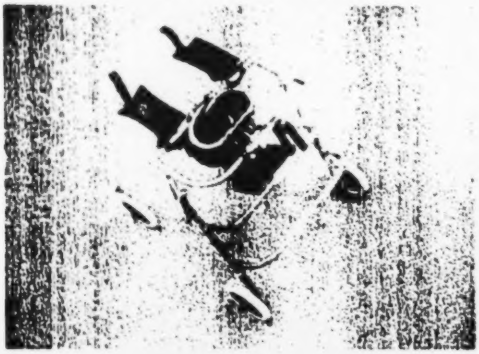

**Figure 1**

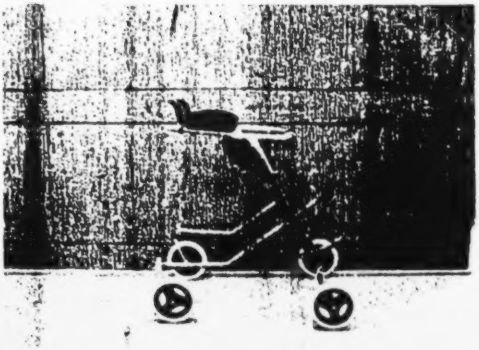

**Figure 2**

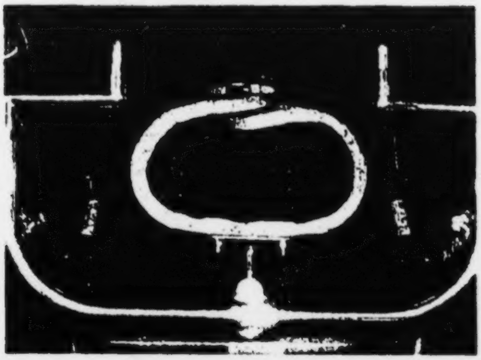

**Figure 3**

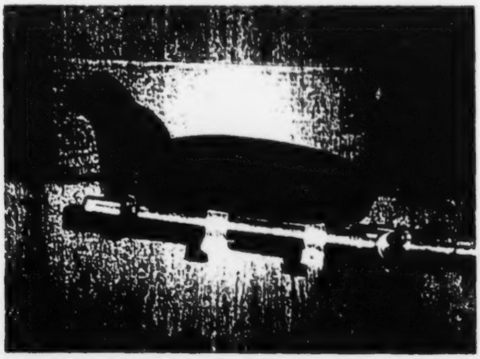

**Figure 4**

We began our project by first meeting with our client, her family, and her physical therapist to identify their needs. This meeting highlighted several features that were important to the overall design of the walker. These features included a rotational hip support, sling seat, and arm rests narrow enough to fit our client. Next, we researched commercial walkers to determine whether or not they could fit our client's needs. Unfortunately, there wasn't a commercial option available that had the array of features that our client desired. After establishing that we would not be able to purchase an appropriate walker, we evaluated whether or not we wanted to buy and modify an existing frame or build one from scratch. We decided to adapt an existing frame, since commercial frames utilize a proven design that has been tested for safety and reliability. They also include a warranty. We found that the *Busy Bee* by Ottobock fit our client's needs the best and would be the easiest to modify (red frame seen in Figures 1 and 2).

After purchasing the *Busy Bee* frame and arm rests, we began the design of the rotational hip support (Figure 3). The design went through several iterations before the final product was fabricated. The hip support was constructed from a hip belt from a backpacking frame pack. A heat-molded polyethylene panel was inserted into the belt to provide rigidity and flexibility. This was then attached to a slotted back plate that allowed for vertical adjustments. The back plate also had a threaded coupling that attached to a boat rail antenna mount, which provided simple rotational adjustment using a single knob. The antenna mount was attached to the rear frame tube, where it can be adjusted horizontally to re-center the client after the hip rotation angle is adjusted.

After testing our design with the client, it was readily apparent that the armrests included with the *Busy Bee* were far too large for our client to use. Therefore, we constructed smaller armrests from bicycle handgrips, metal, foam, and neoprene (Figure 4).

Our client's family and physical therapist were integral in the design of the sling seat. After a preliminary design was conceived, we met with our client's family to determine the final dimensions. Their input was integral to the final device outcome.

## EVALUATION

Overall, the risk of failure in the walker is very low. Of the custom components, the connections of the L angles to the top bar were considered to be the most likely to fail in the event of high loading. For this reason, the setscrew connection between the L-angle and the top bar was modeled in ProMechanica. The total dead load was assumed to be 60 lbs, the estimated maximum weight of the client. After taking into account large factors of safety, dead load multipliers and load distributions over the connections, the model was analyzed. It was found that under such loading the steel would not yield and the deformations would be infinitesimally small. This, combined with numerous client tests, show that the walker will be safe under prescribed conditions.

## DISCUSSION AND CONCLUSIONS

The custom walker satisfies all of our client's needs and provides a safe and reliable product that will promote gait training, increased mobility, and increased independence. The walker will facilitate a greater range of activities since it can be used outdoors. The sling seat also makes our client less reliant on others because she can simply rest in the walker when necessary.

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## ACKNOWLEDGEMENTS

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# Author Index

Acevedo, A., 389
Alden, A., 8
Alexander, M., 175
Algood, D., 285, 321
Alsofrom, B., 75
Alspector, D.E., 62
Ambrosio, F., 282, 285, 371
Ammer, W.A., 23, 297, 321
Ammer, M.L., 333
Anderson, A.E., 383
Armstrong, T.A., 134, 137
Ault, H.K., 160
Axelson, P.W., 155, 377
Axelson, D.A., 155
Bang, W.C., 66
Bauer, S., 309
Bauerschmidt, L.S., 137
Bechtol, J., 315
Bentz, B., 17
Bertocci, G.E., 270, 330
Bhagavathula, P., 386
Bien, Z.Z., 66, 172
Bjorneby, S., 20
Blake, D.J., 345, 348
Blauch, C., 297, 300
Bogie, K., 169
Bonaparte, J.P., 258
Boninger, M.L., 23, 233, 245, 276, 279, 282, 285, 288, 291, 321, 327, 336, 339, 342, 351, 374
Bouchard, D., 118
Brabyn, J.A., 8
Brienza, D.M., 109, 330, 333
Bright, J., 306
Brown, M.A., 383
Buczak, J., 309
Buning, M.E., 227, 245
Cahill, S., 20
Campbell, K., 143
Card, C.L., 5, 17
Chae, J., 169
Chaffin, D.B., 224
Chaves, E., 248, 291
Cherala, A., 386
Christiansen, S., 213
Clark, A., 175
Cohen, L.J., 233, 327
Collins, D.M., 230
Conaway, M.J., 126
Conner, C.P., 29
Cook, A.M., 5, 17, 186
Coolen, A.L., 261, 264
Cooney, D., 392
Cooper, B., 143
Cooper, J., 26
Cooper, R.A., 23, 100, 248, 276, 279, 282, 285, 288, 291, 297, 300, 303, 312, 318, 321, 327, 336, 339, 342, 351, 365, 368, 371, 374, 377
Cooper, R.C., 285, 288, 327
Corfman, T.A., 285, 297, 318, 342, 351
Cronk, S., 129
Dadoo, A., 84
Davis, J.A., 181
DelBoccio, C., 315
Desrosiers, J., 255
Dicianno, B.E., 276
Ding, D., 318
DiSanto, G.L., 152
Dobson, A.R., 288
Duff, P., 20
Duke, S., 189
Dumont, C., 118
Duncan, J.P., 297, 321
Dvorznak, M., 300, 342, 351
Earhart, J.S., 53
Edyburn, D.L., 41, 121, 210
Fay, B.T., 279, 371
Felice, C., 160
Fernie, G.R., 14
Ferrier, N.J., 178
Fitzgerald, S.G., 23, 100, 230, 233, 245, 282, 291, 312, 321, 327, 342, 351, 368, 371
Fronczak, F.J., 29

Fuentes, J., 389
Furumasu, J., 216
Gabriel, N., 35
Gajaria, D., 386
Gallat, S., 315
Gart, M., 26
Gensler, J., 389
Geyer, M.J., 333
Gilden, D., 38
Gilliard, J., 20
Gonzalez, L., 213
Goode, J.W., 29
Gotla, K., 84
Gray, D.B., 252
Guerette, P., 216
Guerette, C., 255
Gunderson, J., 103, 123
Guo, S., 23, 248, 291, 300, 318, 368
Ha, D.R., 270
Hagen, I., 20
Haines, S., 140
Haley, K.J., 32
Hasan, A., 47
Hefzy, M.S., 306
Heier, S.J., 195
Heyman, J.B., 62
Higginbotham, D.J., 75
Hilker, D., 213
Hill, K.J., 69, 78, 81, 84, 87, 106
Hobson, D.A., 273
Hoffman, A.H., 160
Holm, M.B., 230, 245
Holmes, J., 315
Holthe, T., 20
Indermuhle, M., 69
Jenkins, G.R., 236
Jensen, R.P., 324
Jitkreeyarn, P., 354
Karg, P., 330
Karyekar, C., 389
Keeler, C., 360
Kennedy, P., 345, 348
Kim, D.J., 172
Kim, H.Y., 17
Kim, J.B., 66
Kim, S.J., 336
Kirby, R.L., 258, 261, 264, 267
Klein, J.M., 35
Klinkman, M.R., 383
Koester, H.H., 112, 115, 126
Koontz, A.M., 276, 282, 336, 339, 371, 374
Kotasthane, S., 386
Krezman, C., 72
Kukke, S.N., 181
Kwarciak, A.M., 303, 365
Lachance, K.A., 32
LaHaie, H.C., 345, 348
Lake, J., 306
Landry, J., 261
Lane, J.P., 204, 207, 309
Leahy, J.A., 204
Lee, R., 56
Lesher, G.W., 75, 90
Lesperance, F., 118
Levine, S.P., 213
Linder, D., 123
Liu, L., 186
Loesl, S., 44
Longmuir, P.E., 155
LoPresti, E.F., 106, 109, 166
Luebben, A.J., 201
Luk, G., 219
Ma, L., 339
MacLeod, D.A., 258, 261, 264
MacPhee, A.H., 261, 264
Mahadevan, G., 50
Malassigne, P., 44, 324
Martin, J.K., 178, 294
Martinez-Diaz, G., 219
McCartney, T., 297, 300
McCue, M., 233
McNaughton, D., 72
Meng, M.Q.H., 5, 17
Mignatti, M., 47
Mihailidis, A., 14
Miller, D., 166
Miller, J.J., 236
Mills, T., 245
Mispagel, K.M., 155
Moulton, B.J., 75
Nadeau, S., 255
Nelson, A.L., 324

Nemunaitis, G., 306
Nourbakhsh, I., 166
O'Niell, C., 395
Orpwood, R.D., 20
Ostroff, E., 192
Owens, J., 198
Pace, R.J., 149
Palmer, L.O., 53
Palmer Hansen, A.B., 47
Panchang, S., 100
Panchura, C.A., 93
Park, K.H., 66
Park, S.A., 56
Parkinson, M.B., 224
Phantachat, W., 354
Pinnock, K.J., 32
Plaek, E., 360
Pratap, A., 386
Rackensperger, T., 72
Rahman, T., 175
Rajan, P.K., 47
Ramachandran, P., 78
Rathvon, L.P., 324
Raymond, J., 306
Read, T., 357
Reed, M.P., 224
Reeves, S.A., 23, 285, 368
Reinkensmeyer, D.J., 163
Richard, T.G., 178
Richter, W.M., 377
Riemer, R.F., 383
Rigby, P., 143
Rinkus, G.J., 90
Romich, B.A., 69, 81, 84, 87, 96, 106
Rorick, K., 126
Rorrer, R.A.L., 345, 348
Routhier, F., 255
Rowley, A.L., 345
Rucker, B., 392
Ryan, S., 143
Sabelman, E.E., 360
Sachs-Ericsson, N., 230
Sample, W., 175
Sandell, L., 59
Sax, C., 189
Scavina, M., 175
Schmeler, M., 245, 327
Schwanke, T.D., 121, 210, 242
Seagull, A., 84
Seliktar, R., 175
Shapcott, N., 245, 327
Shen, J., 11
Sherman, L., 219
Simpson, R.C., 166
Sindhu, B.S., 242
Smith, C., 261, 264
Smith, R.O., 121, 195, 210, 239, 242
Smith, S.A., 160
Souza, A.L., 279, 282, 336, 371
Spaeth, D.M., 106, 248, 285, 291
Sparnon, E., 59
Springsteen, J.P., 106
Sridharan, P., 50
Sriram, V., 50
Steggles, E., 143
Stone, V.I., 93, 207, 309
Story, M.F., 192
Streilein, K.A., 134, 137
Sujanto, A., 386
Sule, G., 389
Tadepalli, S., 47
Tam, C., 143
Tauke, B., 192
Taylor, A., 186
Tefft, D., 216
Thompson, C., 219
Thorman, T., 312, 327, 368
Topo, P., 20
Toriumi, H., 160
Towers, J.D., 276
Trefler, E., 233, 245
Triolo, R.J., 169, 181
Tungpimolrut, K., 254
Turner, S., 306
Ulin, S.S., 134, 137
Usiak, D.J., 93
Van Roosmalen, L., 273
Vanderheiden, G., 2
Varnhagen, S., 186
Venugopal, A., 50
Vincent, C., 118, 255
Vitek, J.M., 321

Waitzkin, G., 395
Wang, J., 330
Wang, W., 129
Welty, D., 84
Williams, M., 72
Williams, M., 96
Wolf, E.J., 300, 303, 365
Wolgast, M., 389
Wright, D.D., 35
Wynne, J.H., 163
Yang, Y.S., 374
Yap, R., 360
Young, N.A., 106
Young, L.C., 146, 149

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